



EPAG's Presentation to the TRC

- ◆ The following is a summary of the Environmentally Preferred Advanced Generation's (EPAG) presentation to its Technical Advisory Committee (TRC) on October 17-18, 2002. The TRC was convened to critically evaluate the EPAG program and to recommend improvements. In addition to these slides, EPAG staff provided the TRC with a detailed discussion of each program element and answered the TRC's questions. The TRC will prepare a report with its findings and recommendations by the end of 2002.
- ◆ EPAG is one of the six subject areas within the Public Interest Energy Research (PIER) Program. Questions about the EPAG program should be addressed to Mike Batham, EPAG Team Lead, at (916) 654-4548 or by email at mbatham.state.ca.us.



Glossary

Slide Number	Title
3 to 20	PIER Program Overview and Charge to Reviewers (Surles)
21 to 28	EPAG Program Area Overview (Batham)
29 to 36	Mission Statement, Vision, and Goals
37 to 39	Current Projects
40 to 42	Key Accomplishments
43 to 53	Collaborations
54 to 60	Lessons Learned/Corresponding Actions
61 to 65	Future Activities
66 to 143	Discussion of Selected Projects
144 to 146	Tech Review Committee Questions and Comments
(Separate Word File)	Appendix of Active EPAG Contracts



EPAG Technical Review Presentation

**Terry Surles, Ph.D.
PIER Program Manager
California Energy Commission
October 17, 2002**



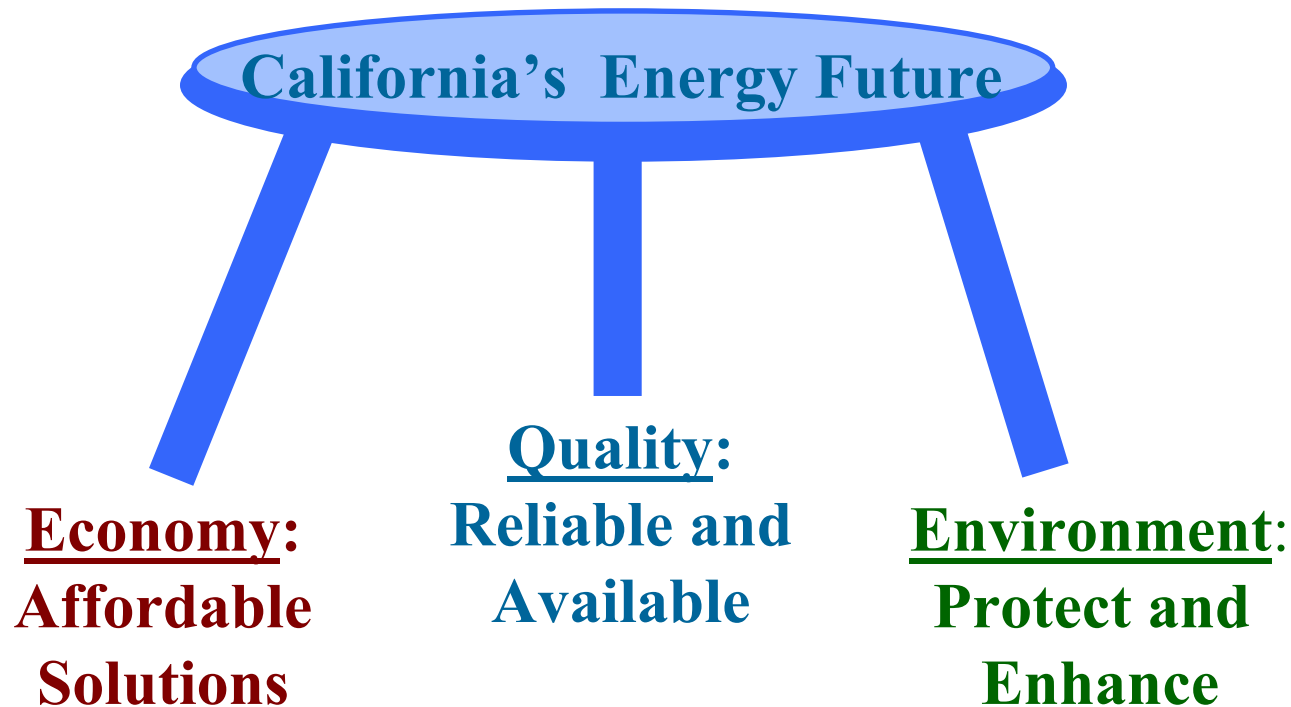
PIER Program Legislative History



- ◆ AB 1890, the Electricity Deregulation Bill, (September 1996) established a new policy (Public Goods Charge) to support
 - ◆ **public interest energy research (CEC/PIER),**
 - ◆ **renewable market support (CEC/Renewables), and**
 - ◆ **energy efficiency market support (CPUC)**
- ◆ SB 90 (November 1997) created the **Public Interest Energy Research Trust Fund**
- ◆ AB 995/SB 1194 (September 2000) continued PIER program for another 10 years (through 2011) at \$62.5 M/yr.



California has Established a \$62M/yr Public Interest Energy Research Program (PIER)

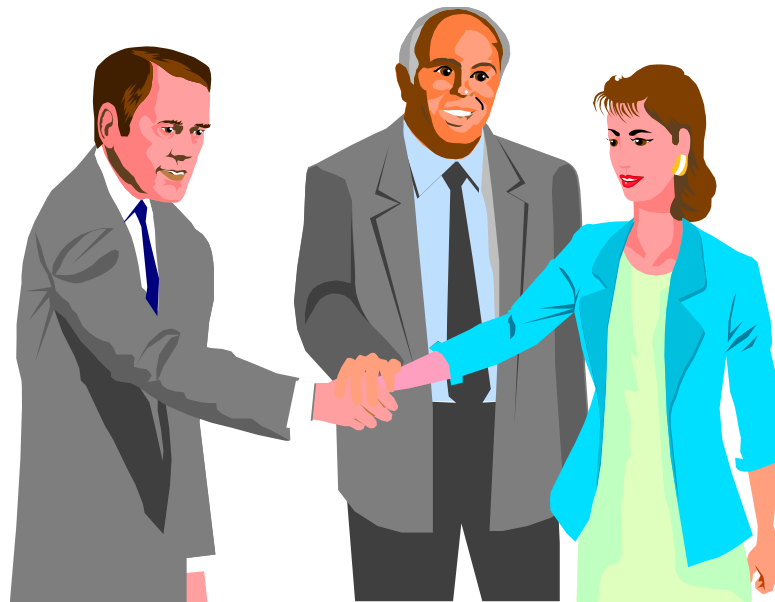




Vision Statement

The future electrical system of California will provide a **clean, abundant and affordable supply** tailored to the needs of “**smart**”, efficient customers and will be the best in the nation.

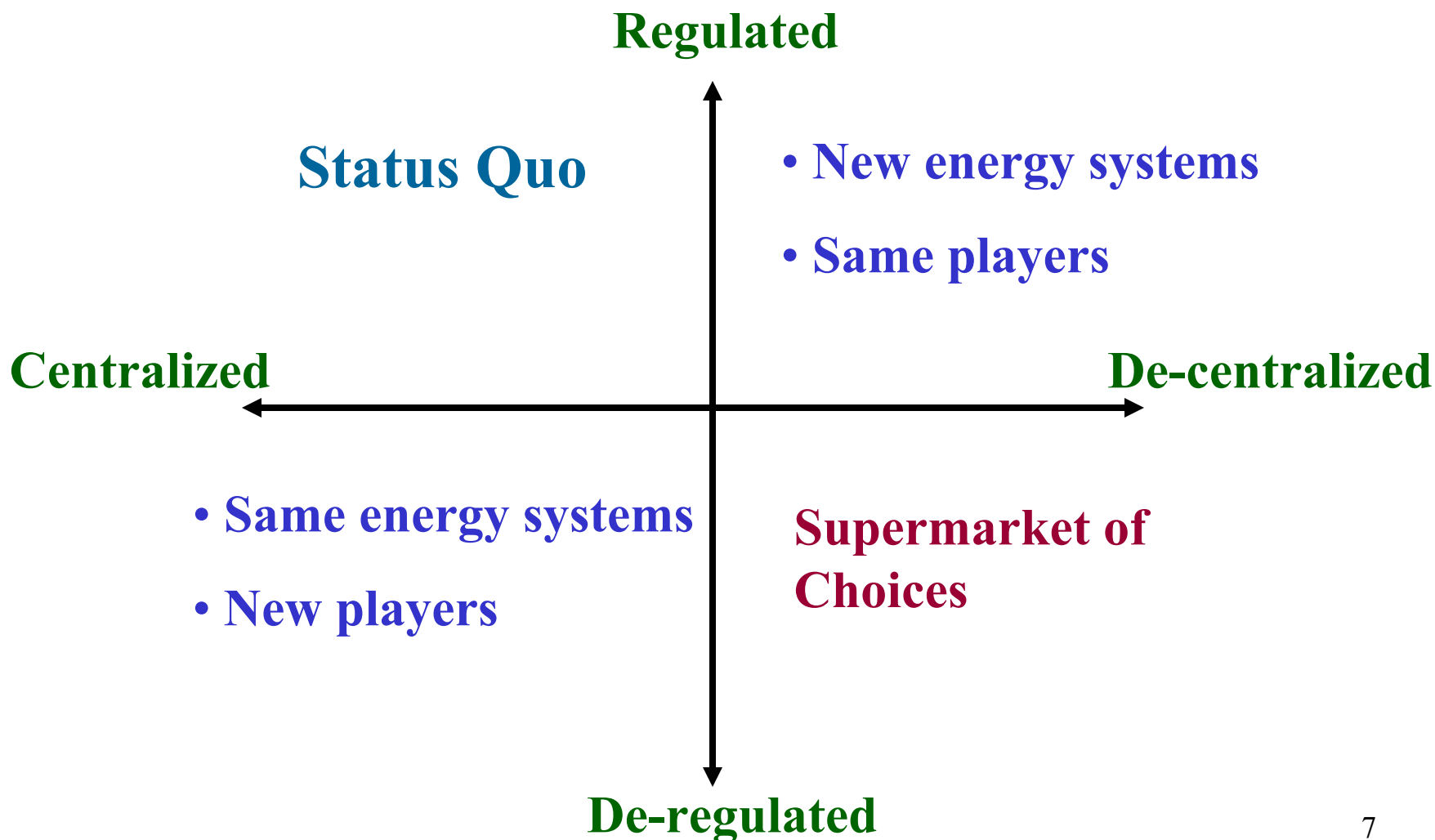
*Tailored,
clean,
abundant,
affordable
supply*



*Smart, efficient
customers*



Our R&D Program Should Impact the Future Energy Marketplace



Another Approach, Scenario Development, for Focusing Efforts

Scenario 1

Controlled/Average Pricing

GOVERNMENT GREENS

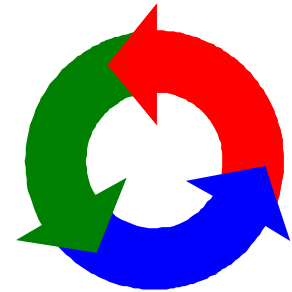


- Government policy leads
- Environment a priority
- Energy as a necessity
- Gov't directed technology

Scenario 2

SUMMER OF 2001 LOOP

- Contentious policy battles
- Energy as a necessity
- Market instability/lumpy investments
- Environmental needs not key



Low environmental priority

High environmental priority

INFORMED ENERGY

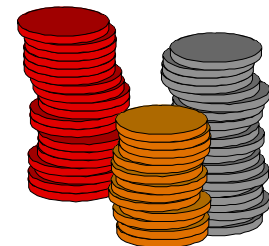


- Energy as a product you buy
- Technology options give choices
- Prices transparent to inform
- Government helps markets develop
- Environmental concerns imbedded in markets

Scenario 3

MARKET COMPETITIVE ENERGY

- Lowest cost energy wins
- Energy as a product you buy
- Technology choices limited by economics
- Environment indirectly addressed by markets



Scenario 4

Transparent/Dynamic Pricing



PIER Mission

The Mission of the PIER program is to conduct public interest energy research that seeks to improve the quality of life for California's citizens by providing environmentally sound, safe, reliable and affordable energy services and products.



PIER Public Benefit Objectives

- ◆ Improve energy cost/value
- ◆ Improve environment, public health, and safety
- ◆ Improve electricity reliability/quality/sufficiency
- ◆ Strengthen the economy
- ◆ Provide consumer choice

We are using Decision Analysis to improve quantitative understanding of how PIER is meeting these objectives



Attributes for Addressing State Issues

Program Integration

Balanced Technology Portfolio

- Temporal
- Technology
- Risk

Technology Partnerships

- Universities
- Industry
- Federal
- State
- Local

Focus on California

- Specific to State needs



California Must be Prepared to Face the Same Issues as Others

◆ Economics

- ◆ **Resource Competition**
- ◆ **New technology market penetration**
- ◆ **Lifecycle analysis**

◆ Environment

- ◆ **Local regional and global impact**
- ◆ **Climate change**
- ◆ **Sustainable practices**

◆ Systems

- ◆ **Peak demand**
- ◆ **Infrastructure integration**



Energy Costs Fundamentally Affect our Overall Economy



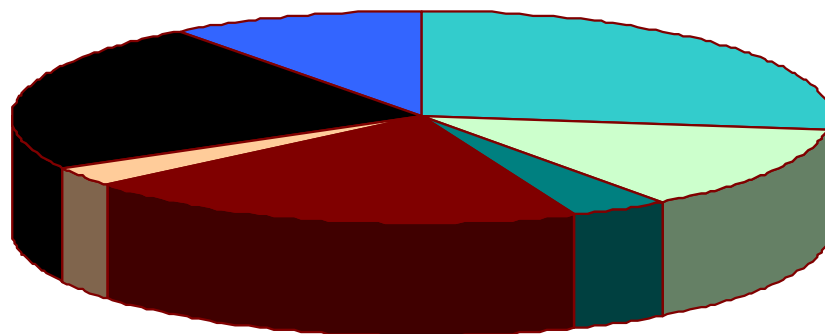
Characteristics Unique to California



- ◆ Population shifts to hotter, inland areas
- ◆ California building, appliance, and emissions practices and standards are tied to our R&D activities
- ◆ Water quality/quantity issues
- ◆ Climate characteristics
- ◆ Nature of emissions offsets, NO_x allowances
- ◆ Seismic vulnerability
- ◆ Concerns over electricity restructuring increases “the uncertainty bandwidth”



PIER RESEARCH PARTNERS



- **Utilities (27%)**
- **University (13%)**
- **Large Business (4%)**
- **Small Business (20%)**
- **State (3%)**
- **Non-Profit (23%)**
- **National Labs (10%)**



Six PIER Subject Areas

- ◆ Renewable energy
- ◆ Environmentally-preferred advanced generation
- ◆ Residential and commercial buildings end-use energy efficiency
- ◆ Agricultural and industrial demand side technologies
- ◆ Energy-related environmental research and assessment
- ◆ Energy Systems Integration



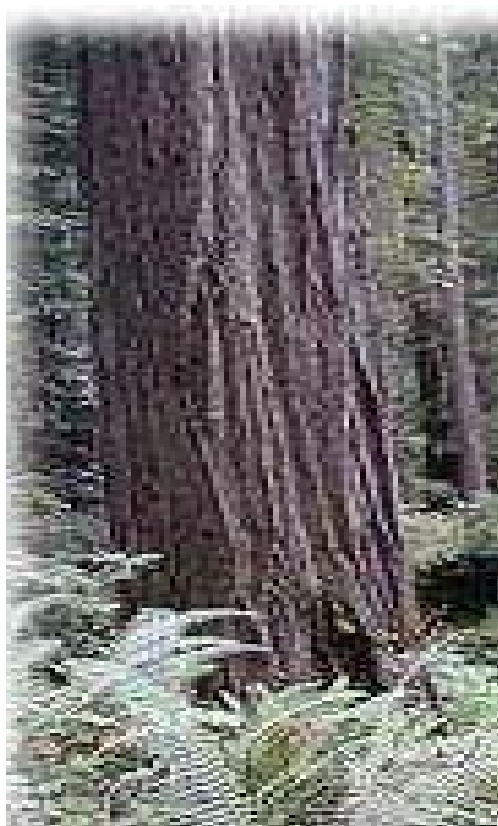
PIER Projects Related to Major Topics Funding (in millions 9/02)

Supply Renewables, EPAG	\$101
Demand Buildings, Ind/Ag/Water	\$61
System / Environment Strategic, Environmental	\$56

Currently, \$167M in open contracts, \$30M pending



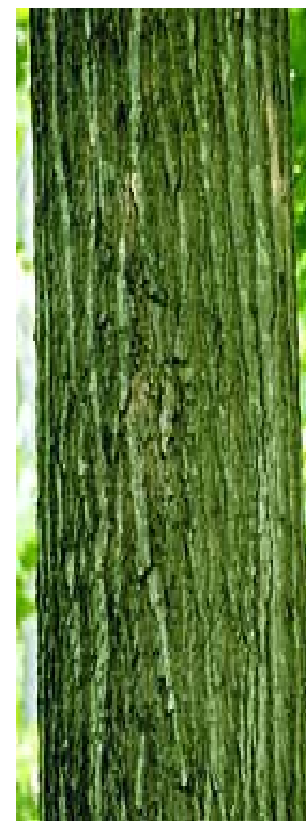
The CEC/PIER Program: Two Redwoods and an Oak



Efficiency



DER



Environment



Some Areas We Will be Developing in the Near-Term

◆ Efficiency

- ◆ Zero-energy housing
- ◆ AWWARF collaboration
- ◆ Electronics/Food-Ag IOF
- ◆ CA optimized AC
- ◆ Lighting
- ◆ Indoor air quality

◆ Environment/Climate

- ◆ Regional climate studies
- ◆ Zero-emission generators
- ◆ Environmental evaluation and mitigation

◆ Distributed Energy Resources

- ◆ Combined heat and power
- ◆ Solid oxide fuel cells
- ◆ Communications, Control, Information system
- ◆ Interconnection standards
- ◆ Storage technology

◆ Cross-Cutting

- ◆ Multi-state, Federal collaboration on DER testing standards



Goal for Technical Review:



How Do We Make the Program Better?

- ◆ Comments on the past - lessons learned (or should have learned)
- ◆ Advice on modifications to current portfolio
- ◆ Insight and expert opinion on future directions
- ◆ Comments appreciated on:
 - ◆ **integration with the rest of PIER**
 - ◆ **integration with the rest of the CEC**
 - ◆ **role of R&D in a state government**
 - ◆ **internal state process**
 - ◆ **integration with other energy R&D programs**



General Comments for the Future: How We Will Use Your Recommendations

- ◆ PIER has to be extended to 12/31/11
- ◆ Investment plan signed into law on 9/12/02,
Good to 12/31/06 - without “urgency”. Thus,
 - ◆ Available funds (from 1/1/02) are on hold until 1/1/03
 - ◆ We will implement your advice in allocating ~ \$150M for projects over the next two fiscal years



EPAG Program Overview

◆ Introductions

- ◆ Mike Batham (EPAG Area Lead)
- ◆ Mike Magaletti (EPAG Area Supervisor)
- ◆ Arthur J. Soinski, John Beyer, Jack Janes, Avtar Bining, Allan Ward

◆ EPAG is *Environmentally* Preferred Advanced Generation



EPAG History

- ◆ Stakeholder meetings were held in 1998
 - ◆ Lead to June 20th, 1999 EPAG Plan for Research
- ◆ Need to address important issues
 - Reducing the cost of electricity through significant advances in generation efficiency are limited by the technologies currently used in commercially available generation systems.
 - System reliability and the cost of electricity are adversely affected by California's large inventory of outdated steam power plants.
 - New cost-effective pollution control technologies are needed to reduce the health and environmental impacts from power plant emissions.
 - Small and intermediate scale environmentally-preferred power generation technologies and systems are needed that can be efficiently and cost-effectively used as distributed generation resources.



EPAG History-continued

- ◆ **EPAG has increasingly focused its RD&D expectations over time**
 - ◆ Energy Technology Advancement Program
 - ◆ Member Requests
 - ◆ Defense Conversion Grants



EPAG History-continued

◆ Transition Contracts 1997

- 3 EPAG contracts, \$2.8 Million
- Continued funding of meritorious public interest energy research initiated by utilities
- Contractor-specified project goals



EPAG History-continued

- ◆ **PIER First and Second General Solicitations 1998 & 1999**
 - ◆ 6 EPAG contracts, \$5.3 Million
 - ◆ Prior to development of specific R&D targets or goals
- ◆ **1999-to date Staff generated and unsolicited proposals**
 - ◆ 6 contracts, \$5.7 Million
 - ◆ Actual projects

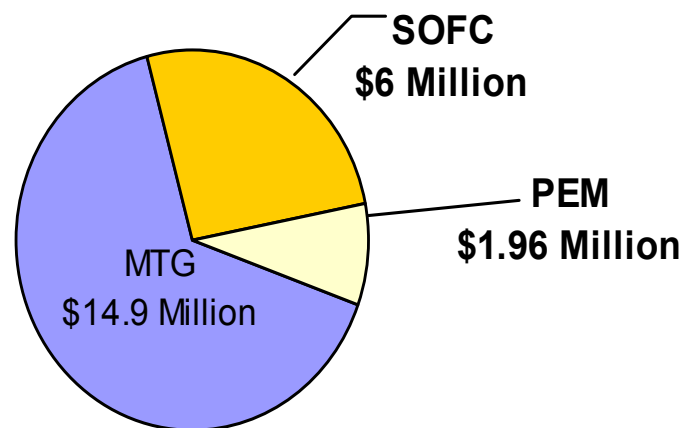


EPAG History-continued

◆ Targeted Fuel Cell and Microturbine Solicitation 2001

- ◆ 9 contracts, \$22.8 Million
- ◆ Performance Targets Established
- ◆ Coordinated with DOE MTG targets and SECA goals

2001 Targeted Solicitation by PIER Funding





EPAG History-continued

◆ Targeted ARICE RFP 2002

- ◆ 2 projects, \$5 Million
- ◆ 3rd possible project
- ◆ Coordinated with Federal ARES performance targets

◆ EISG Solicitations (ongoing)

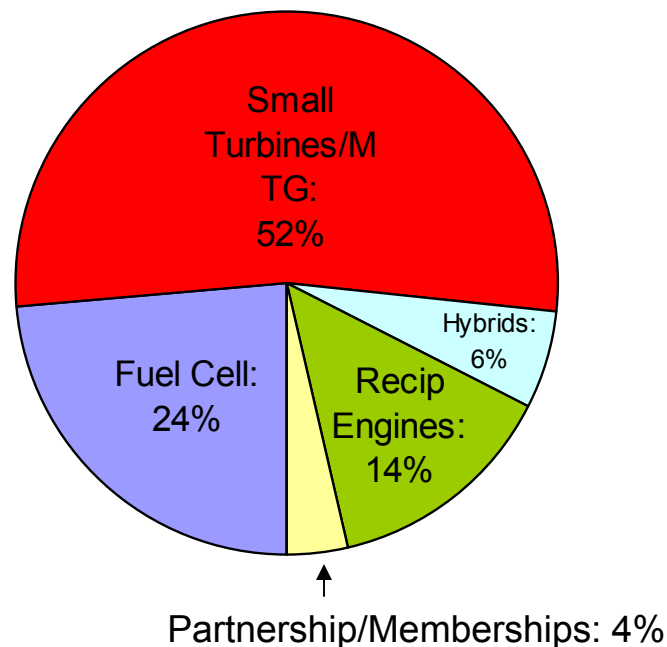
- ◆ 22 funded projects, \$1.6 million in funding



Completed EPAG Projects

- ◆ 4 Fuel Cell
- ◆ 2 Small Turbine/MTG
- ◆ 1 Hybrid
- ◆ 1 Reciprocating Engine
- ◆ 2 Partnership/Memberships
- ◆ 2 Other

Completed projects by PIER Funding





EPAG Mission

To develop a balanced portfolio and competitive mixture of technologies that will provide value, including efficient utilization of resources, as well as clean, reliable, and high-quality electricity for California.



EPAG Vision

California end-users will be able to obtain well-characterized distributed generation systems that are environmentally friendly and are competitive.



EPAG Goals

- ◆ **Enhance the likelihood of commercial success through active collaborations with the energy industry, DOE, state energy agencies, utilities, regulators, and policymakers.**
- ◆ **Leverage project funding with federal and other state energy programs by coordinating RDD&C programs and activities.**



EPAG Goals continued

- ◆ **Remove constraints to the procurement and use of commercially available DG technologies.**
 - ◆ Develop and commercialize technologies or operating strategies to minimize emissions to meet CARB standards for unlimited operation.
 - ◆ Develop and maintain a publicly-available performance database for DG systems.



EPAG Goals continued

- ◆ **Increase the market acceptance of emerging EPAG technologies.**
 - ◆ Characterize system performance by developing and implementing standardized performance testing, evaluation, reporting, and database protocols.
 - ◆ Develop standardized DG system designs and installation procedures.
 - ◆ Develop smart system diagnostics, dispatchability, and monitoring capability for DG systems.



EPAG Goals continued

- ◆ **Maintain leadership in RDD&C related to EPAG systems and technologies.**
 - ◆ Establish technical and economic performance targets and stretch goals for EPAG system cost and performance.
 - ◆ Update and publish an EPAG RDD&C plan every two years.



EPAG Goals continued

- ◆ **Develop next generation technologies that significantly improve performance and reduce costs.**
 - ◆ Collaborate with R&D organizations on potential evolutionary technologies
 - ◆ Establish new performance stretch goals by technology type



EPAG Goals continued

- ◆ **Explore and evaluate revolutionary concepts that offer breakthrough potential in generation technology and cost.**



Current Projects

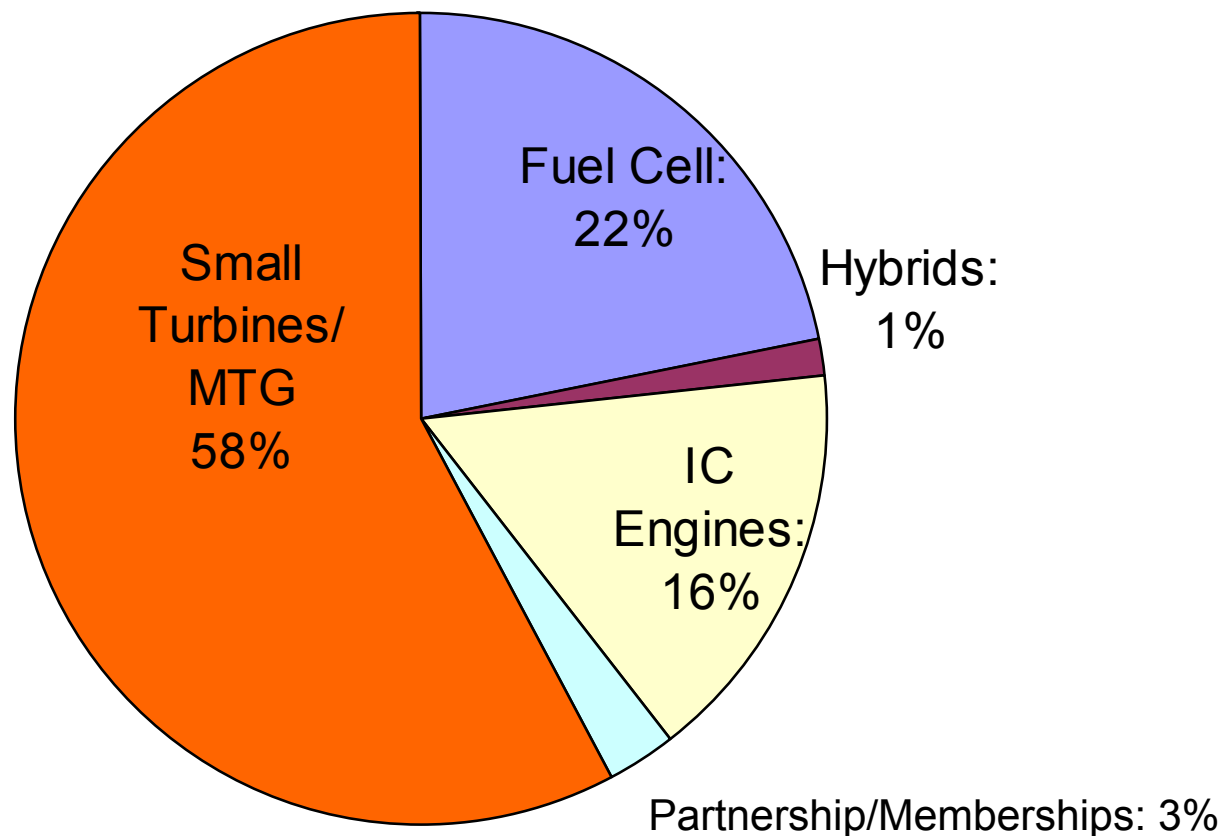
◆ Portfolio of Active Projects

- ◆ Fuel cells (4 projects, \$8.3 Million)
- ◆ Hybrid (1 project, \$500k)
- ◆ Reciprocating engines (3 projects, \$6 Million)
- ◆ Turbines (13 projects, \$21.7 Million)
- ◆ Partnerships/memberships (12 projects, \$1.1 Million)

◆ Technical support to others



Active Projects by PIER Funding





Current Projects Compared to Goals



Technology Types	Number of Projects with Major Impact on Goals						
	Collaboration	Leverage Funding	Remove Constraints to Procurement & Use of Commercially Available DG	Increase the Market Acceptance of Emerging EPAG Tech	Maintain Leadership Role in EPAG RDD&C	Develop Next Generation Tech. that Improves Performance & Reduces Costs	Explore Revolutionary EPAG RDD&C Concepts
Fuel Cells	2	3	2	1	1	2	1
Hybrid	1	0	1	0	1	0	1
Reciprocating Engines	2	0	3	3	3	3	0
Turbines	7	10	10	6	8	8	2
Partnerships/ Memberships	2	2	2	2	1	1	0



Key Accomplishments

- ◆ Prepared a Subject Area Research Plan
- ◆ Focused on technologies with DG applications
- ◆ Accelerated low NO_x technologies
- ◆ 4 promising projects were awarded follow-on funding
- ◆ 4 projects unlikely to be successful were canceled
- ◆ Improved EPAG effectiveness in focusing projects
 - Targeted RFPs
 - Staff generated contracts



FY 1999/2000 Environmentally Preferred Advanced Generation Subject Area Research Plan



Targeted Research Using Competitive Negotiation or RFP (\$9.35 million)

Advanced Turbine Generators

- Microturbine (MT) Demo & Testing (\$500k)

- Targeted MT Development (\$2,000k)
- Combustor Design Tool Development (\$350k)

- Targeted Flexible Midsize Turbine Development (\$1,500k)

Fuel Cells

- Targeted FC Development (\$2,000k)
- Total FC Power Plant System Performance (\$300k)

Cross-Cutting and Other EPAG Technologies

- Power Conditioner Unit (\$200k) *
- Targeted MT/FC Hybrid (\$1,500k)
- Targeted Reciprocating Engine (\$1,000k)

Interagency Agreement or Sole Source Contract (\$3.6 million)

Advanced Turbine Generators

- Development of Ultra-Low NOx Surface Stabilized Combustor (\$1,000k)

Fuel Cells (FC)

- Residential-scale FC Demo (\$500k)
- Dynamic Models for FC Systems (\$400k)
- FC Performance Analysis Tools (\$300k)

Cross-Cutting and Other EPAG Technologies +

- Innovative Projects Grants (\$1,000k)

Program Support

- Long-Term DOE MOU (\$400k)

Memberships or Tech Support (\$0.55 million)

Cross-Cutting and Other EPAG Technologies

- EEPRI Memberships (\$155k) *
- GGRI Memberships (\$68k) *

Program Support

- EPAG Technology Roadmapping (\$330k)

* These projects are being co-funded with at least one other PIER program area. The estimated cost in this table is only the EPAG portion of the total cost.

+ Only successful EPAG projects selected competitively in the Small Grants Program will be eligible.



Key Accomplishments continued

- ◆ Improved EPAG contract management
 - Established Contract CPRs as milestones and decision points
- ◆ Conducted technical reviews with DOE & NYSERDA
- ◆ Engaged in multiple collaborations



Current collaborations

- ◆ External collaborations
 - ASERTTI/NASEO
 - ARICE, ARES-DOE
 - Ramgen, ATS-NETL
 - National Fuel Cell Research Center (NFCRC)
 - FEMP CHP at federal facilities
 - GRDA proposal review and geotechnical expertise
- ◆ Internal collaborations with other PIER areas
 - DG, CHP, C.O.P.E..



DG collaborations

- ◆ DG is a major focus for PIER-- eighty-five projects totaling \$84 million (out of over \$372 million of total PIER funds).
 - ◆ **The 85 projects include DG related projects managed directly by the PIER program areas; projects under the small grant program are excluded**
 - ◆ **As of 10/8/02, 8 projects are completed, 74 projects are ongoing and 3 are planned**
 - ◆ **All six PIER program areas have ongoing or planned projects that are DG related**
 - ◆ **There is at least one research project related to every area**



DG Collaborations continued



Numerous issues were identified as part of the CEC Siting Commission DG Strategic Plan development process.

DG Issues	
A. Environmental Impact	<ul style="list-style-type: none">• When will DG technologies have a positive impact on the environment?• Should clean DG technologies be subsidized or otherwise encouraged?• Should DG be used to improve air quality?• Should DG improve worker health and safety?
B. Low Cost Power	<ul style="list-style-type: none">• Can DG be competitive with central power generation?• Should customers have the choice of DG to reduce power cost?• Is DG the most economically efficient approach to generating and delivering power to customers?
C. Generation Reliability	<ul style="list-style-type: none">• Will DG improve customer power reliability?• Can customers use DG for high reliability and power quality needs?
D. Grid Effects	<ul style="list-style-type: none">• Will DG improve grid reliability?• Will DG have a positive or negative effect on the power system?• Can grid effects be monetized and allocated to stakeholders?• How can the locational value of DG be exploited?• How can you measure and reward consumers for the grid benefits they generate through use of DER?
E. Interconnection	<ul style="list-style-type: none">• Should technical requirements, processes and contracts be modified for DG?• Can DG be safely and cost effectively interconnected with the power system?• Is plug and play possible for DG interconnection?
F. Siting & Permitting	<ul style="list-style-type: none">• Should siting and permitting requirements be modified for DG?
G. Integration	<ul style="list-style-type: none">• How can DG be integrated with California's current system operations?• How can the system be operated to optimize DG?
H. Market Structure	<ul style="list-style-type: none">• How can DG be integrated with California's current market structure?• Can the market structure be changed to create a win-win for all stakeholders?• How can utilities be incentivized to participate and/or encourage DG?• Can a market structure be created that will allow DG to compete?• Should California use net metering?

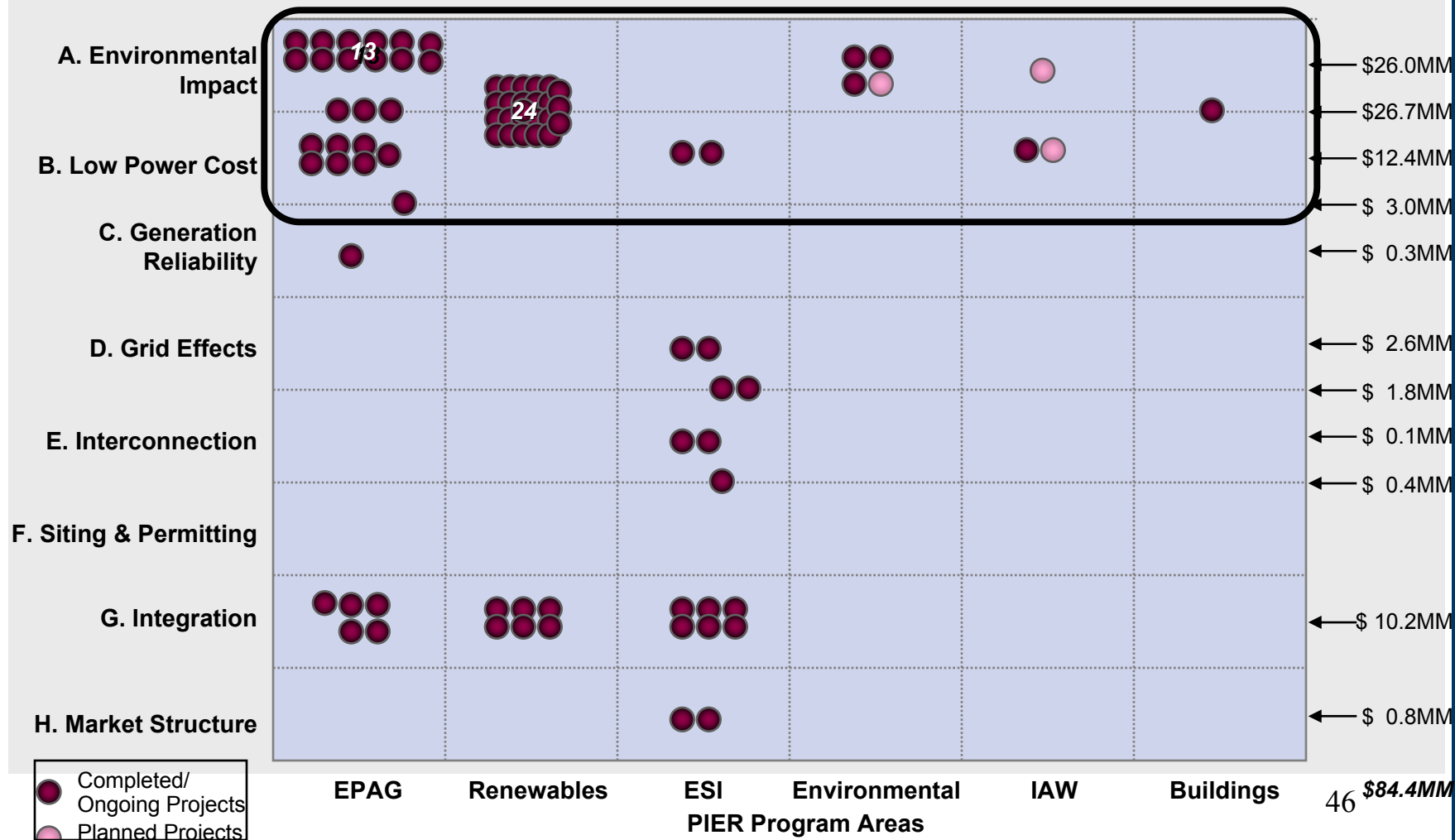
Note: Issue candidates are not listed in any particular order



DG Collaborations continued



Eighty-one percent of the PIER DG portfolio is focused on reducing environmental impact and developing lower cost power.





Technical assistance to other R&D organizations

- ◆ CA Power Authority
- ◆ CARB (SB 1298, ICAT, ARICE)
- ◆ DOE
- ◆ NYSERDA
- ◆ EPRI DG Target Advisory Committee



Example EPAG Collaboration



California Advanced Reciprocating Internal Combustion Engines (ARICE)



California ARICE Collaborative

Purpose

- ◆ **The purpose of the Collaborative is to facilitate the (RDD&C) of (ARICE) systems that are super-efficient and ultra-clean for use in California.**
- ◆ **ARICE Collaborative stakeholders ~ 200**



(ARICE) systems should do one or more of the following:

- ◆ meet or exceed California emissions requirements and have other desirable environmental attributes;
- ◆ improve fuel-to-electricity conversion efficiency;
- ◆ increase the overall energy use efficiency through CHP;
- ◆ lower or maintain current capital, installation, O&M, and/or life cycle costs;
- ◆ improve and increment RAMDU;
- ◆ have multi-fuel use capabilities;
- ◆ support integration and aggregation of distributed generation and on-site generation with the power grid;
- ◆ coordinate with CEC Transportation Office and share results



ARICE

Accomplishments to date

- ◆ **Developed a California ARICE Collaborative Plan**
- ◆ **Formed a Core Group - (CEC, USDOE, ARB, SCAQMD, NRDC)**
- ◆ **Identified the Advisory Group (Core Group plus OEMs (EMA), National Labs, Universities, Utilities, Fuel Suppliers, R&D Companies, and others.)**
- ◆ **Held first CA ARICE Collaborative Workshop on July 10, 2001.**
- ◆ **Released an RFP with specific performance targets on December 7, 2001 (up to \$6 million)**
- ◆ **Two contracts (Waukesha - \$3M and LLNL - \$2M) awarded and work started by September, 2002**
- ◆ **Advanced Ignition Systems (AIS) Roundtable Meeting at ANL (Argonne, IL) during October 8-9, 2002 to build a consortia.**



Performance Targets for ARICE RFP



Parameter	2003	2005	2007	2010
Efficiency				
Brake Thermal Efficiency	>40%	>42%	>45%	>50%
Fuel-to-Electric Efficiency*	>38%	>40%	>43%	>50%
Overall Efficiency (CHP)	>85%	>85%	>86%	>88%
Emissions – shaft power (g/bhp-hr)				
Oxides of Nitrogen (NO _x)	<0.15	<0.15	<0.015	≈0.01
Carbon Monoxide (CO)	<1.77	<1.77	<0.02	<0.02
Volatile Organic Compounds (VOCs)	<0.3	<0.3	<0.006	<0.006
Particulate Matter (PM10)	<0.01	<0.01	<0.01	<0.01
Emissions – power generation (lb/MW_ehr)				
Oxides of Nitrogen (NO _x)	<0.5	<0.5	<0.05	≈0.03
Carbon Monoxide (CO)	<6.0	<6.0	<0.08	<0.08
Volatile Organic Compounds (VOCs)	<1.0	<1.0	<0.02	<0.02
Particulate Matter (PM10)	<0.03	<0.03	<0.03	<0.03
Cost				
Complete Installed Cost (\$/kW _e)	<800	<750	<700	<600
O&M Cost (\$/kW _e h)	<0.006	<0.005	<0.005	<0.004
Availability & Durability				
Availability	>88%	>90%	>92%	>95%
B10 Durability (hours)	>8,000	>9,000	>10,000	>12,000
Mean Time Between Major Overhaul (hours)	>35,000	>40,000	>45,000	>50,000



Advanced Ignition Systems Roundtable

October 8 - 9, 2002

- ♦ US DOE initiated roundtable to build consortia for developing advanced ignition systems such as Laser Based Ignition Systems (LBIS)
- ♦ Organized by ANL; Invited participants - US DOE, CEC, ANL, LLNL, NETL, ORNL, Sandia NL, Colorado State University, Caterpillar, Cummins, Waukesha, SwRI, Altronic.. ~25 participants
- ♦ Concerted effort by all, under a **single umbrella contract**, to deliver Advanced Laser Ignition System (ALIS) integrated ARICE within 2-3 years meeting or exceeding California's DG emission standard and ARICE performance targets?



Lessons Learned/Corresponding Actions

- ◆ Not all research organizations are motivated by or skilled at commercializing new technologies.
 - **Require contract teams to have commercialization experience/expertise and preferably a commercialization partner.**
 - **Require commercialization and technology transfer goals and deliverables in contracts.**
 - **License technology to commercialization partner, but maintain and exercise march-in rights if commercialization lags.**



Lessons Learned /Corresponding Actions continued



- ◆ Insufficient staff to effectively manage the increasing number of projects.
 - **Fund subsequent phases of technically successful projects.**
 - **Fund fewer, higher dollar amount contracts.**
 - **Conduct programmatic solicitations with the lead contractor managing multiple related projects.**
 - **Use more technical support.**



Lessons Learned/Corresponding

Actions continued

- ◆ Energy technology and market environments are dynamic and subject to rapid change.
 - **Use Critical project Reviews (CPRs) to assess both technical progress and the project's continued relevance to market, and continued conformance to public policy.**
 - **Modify Statements of Work (SOWs) or cancel contracts that are not likely to be successful.**



Lessons Learned/Corresponding Actions continued



- ◆ Staff DG expertise is not effectively shared among PIER or CEC groups
 - **Participate in program planning, RFP development, proposal reviews, and CPRs on DG related contracts.**
 - **Participate in joint planning of DG activities.**
 - **Provide a central CEC contact for DG policy development and program implementation.**



Lessons Learned/Corresponding Actions continued

- ◆ EPAG technology development is occurring throughout the world.
 - **Adapt and/or demonstrate technologies as needed to meet unique California needs and conditions.**
 - **Maximize the use of collaboration to identify new EPAG activities and priorities.**
 - **Perform status reviews of EPAG technologies.**



Lessons Learned/Corresponding Actions continued

- ◆ Projects with a clearly identified technology development path have high potential to produce near term benefits.
 - **Assure that project teams understand commercialization issues and have identified a path to the market place.**
 - **Fund EPAG technology systems in preference to components.**



Lessons Learned/Corresponding Actions continued

- ◆ Difficult to maintain expertise in multiple technical areas while managing contracts, issuing RFPs, evaluating proposals, and developing SOWs.
 - **Use stakeholder groups and scoping studies to identify issues and recommend new program priorities.**
 - **Hold regular technical reviews of specific EPAG technology areas.**



EPAG Emphases for the Future

- ◆ Prioritize and leverage RDD&C activities to optimize limited staff resources.
- ◆ Focus EPAG activities on fewer and higher priority California electricity problems.
- ◆ Measure project and EPAG success by the expected commercial market impact.
- ◆ Make judicial use of Critical Project Reviews and redirect or terminate contracts that are not meeting expectations.
- ◆ PIER staff assumes ownership of project and contract goals, progress, and commercialization.



Future Activities

- ◆ Short term < 5 years
 - ASERTTI/NASEO State Technology Advancement Collaborative (STAC) (\$6-11 million first year)
 - CHP RFP (Early 2003)
 - Scoping study contract
 - FEMP, CHP at Federal Facilities
 - Explore collaboration opportunities; DOE, EPA, FEMP, etc.
 - » coordinate with other PIER Areas
 - » establish consortium specific stretch goals
- ◆ ARICE Advanced (Laser) Ignition Consortia



Future Activities continued

- ◆ Short term continued
 - Stirling engine demonstration w/EPRI
 - Conferences-SECA, CHP, Hybrids
 - Vision 21 (Monitor DOE)
 - SECA (Monitor DOE)
 - Follow-on projects
 - Unanticipated meritorious opportunities
 - EISG phase II



Future Activities continued

- ◆ Midterm 5-10 years
 - Ramgen
 - Adapting low NO_x technologies to large turbines
 - Fuel cells (stay current)
 - High efficiency hybrids (stay current)
 - Fuel cell/hybrid RFP
 - EISG phase II
 - GE Advanced Turbine “7H” Demonstration
 - GE 10 Low NO_x Combustor



Future Activities continued

- ◆ Long term > 10 years
 - Hydrogen fueled economy
 - Identify RDD&C Issues
 - Determine if EPAG has a role
 - » Avoid duplicative work by other agencies
 - » Leverage funds/resources with other agencies
 - CHP/P Combine Heat Power and Power



Discussion of selected projects

- ◆ Catalytica
- ◆ Clean Energy Systems
- ◆ Siemens Westinghouse hybrid
- ◆ GTI solid oxide fuel cell system
- ◆ ASERTTI



Ultra Low Emissions for Gas Turbines

- ◆ Meet or exceed emissions limitations
- ◆ Develop low emissions combustion technologies for gas turbines, without exhaust gas cleanup.
- ◆ Current focus on micro and small turbines (<20 MW) used for DG, but the technologies are applicable to central plant size turbines.



Catalytica's Xonon[®]
catalytic combustor
on a Kawasaki turbine.



Benefits of Combustion with Ultra Low Emissions



- ◆ Pollution prevention, not pollution cleanup.
- ◆ Eliminates the need for selective catalytic reduction (SCR).
- ◆ No ammonia. Avoids the dangers of transportation and storage, and ammonia slip in exhaust gas.
- ◆ Reduces emissions from gas turbines to less than current standards. May become BACT.
- ◆ Makes turbines more acceptable in heavily populated areas.
- ◆ Reduces the footprint of gas turbine installations, lowering capital costs for land and structures.



Evolution of Low Emissions Combustion Technologies with PIER Support



1998 - 2001

- ◆ **Catalytica Energy Systems** \$1,300,000 PIER
(RAMD) demonstration of Xonon[®] catalytic combustion on a 1.4 MW Kawasaki turbine at Silicon Valley Power (City of Santa Clara).
- ◆ **Alzeta** \$880,000 PIER
Design, build and test a prototype combustor using surface stabilized combustion for 10 kW to 5 MW turbines.
- ◆ **Solar Turbines** \$800,000 PIER
Implement Xonon[®] on Centaur 50 (4.5 MW) and Taurus 60 (5.2 MW) turbines.

2000 - 2001

- ◆ **Alzeta** \$1,300,000 PIER
Test the surface stabilized combustion system on an operating microturbine.



Targets & Stretch Goals for Micro & Small Gas Turbines in April 2001 RFP



Parameter	Target	Stretch Goal
Engine Fuel Efficiency	36%	40%
Emissions	<7 ppm NOx <20 ppm CO <20 ppm UHC	<3 ppm NOx <10 ppm CO <10 ppm UHC
Availability	80%	90%
Reliability	93%	98%
Capital Cost, FOB	\$600/kW	\$500/kW
Mean Time Between Overhaul	12,000 hours	16,000 hours
Serviceable Life	36,000 hours	48,000 hours
Performance Degradation	<10% (over MTBO)	<5% (over MTBO)
Multi-Fuel Capability	2 Premium fuels 1 Bio-derived fuel	3 Premium fuels 2 Bio-derived fuels Variable



Continuing PIER Support for Low Emissions Combustion

2001-2005

- ◆ **Alzeta and Solar Turbines** \$2,400,000 PIER
Develop Alzeta's surface stabilized combustion system for Solar's Titan 130 (13.5 MW).
- ◆ **Solar Turbines and Catalytica** \$3,000,000 PIER
Test Catalytica's catalytic combustion, Alzeta's surface stabilized combustion, and Precision Combustion's rich/lean catalytic combustion. Perform engine tests with the preferred technology on a Taurus 70 (7.5 MW).
- ◆ **Catalytica Energy Systems** \$3,000,000 PIER
Develop and demonstrate catalytic combustion on a multi-can gas turbine.



Continuing PIER Support for Low Emissions Combustion



2002 - 2005

- ◆ **Sonoma Developmental Center** \$105,000 PIER
 - ➔ First commercial installation and demonstration of Catalytica Xonon[®]-equipped turbine (1.4 MW Kawasaki).
 - ➔ First DG, CHP application (electricity and steam for 120 buildings).
 - ➔ NO_x reduced from current 30 ppm to <2.5 ppm.
 - ➔ First use of standardized performance testing and evaluation protocols developed for microturbine generators by UC Irvine under contract with the CEC.
- ◆ **Riverside Public Utilities / Alliance Power** (pending)
Installation of Xonon[®] on GE-10 (11 MW) turbine next to three GE-10s peaking units equipped with Dry Low NO_x (DLN).



Challenges for Catalytic Combustion Technologies

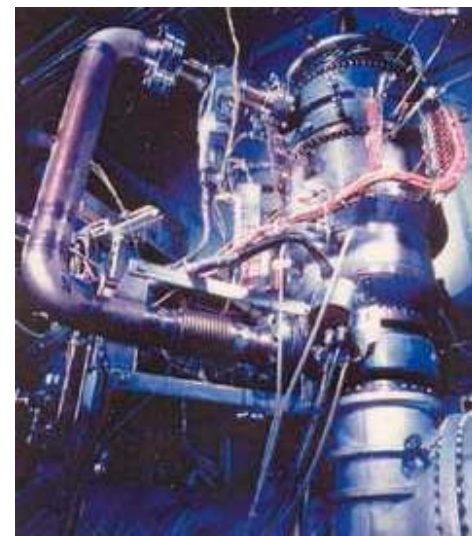
- ◆ Increased catalyst life
- ◆ Increased fuel efficiency
- ◆ Reduced cost
- ◆ Controls for multi-can turbines
- ◆ Reduced size
- ◆ Configurations for retrofit on existing turbines
- ◆ Multi-fuel capability
- ◆ Performance at partial load
- ◆ Acceptance by power generation industry



Silicon Valley Power, Santa Clara, CA



RAMD demo of Catalytica's Xonon combustor





Successes with Catalytic Combustion



1999-2001

- ◆ **Silicon Valley Power, Santa Clara, CA** \$1,300,000
RAMD demo of a Xonon[®]-equipped, grid-connected
1.4 MW Kawasaki turbine.
 - ➔ 8100 hours of 24/7 operation completed in June 2001.
 - ➔ Performance at full load:
 - NO_x < 2.5 ppm (corrected to 15% O₂)
 - CO < 6 ppm (corrected to 15% O₂)
 - UHC < 3 ppm
 - Reliability > 98%
 - Efficiency = 23% (Heat rate = 15,000 btu/kW_e-h)
 - ➔ EPA "achieved in practice" designation for Xonon[®] as an emissions control technology
 - ➔ EPA's first Clean Air Excellence Award
 - ➔ California Air Resource Board (CARB) pre-certification of Xonon[®]



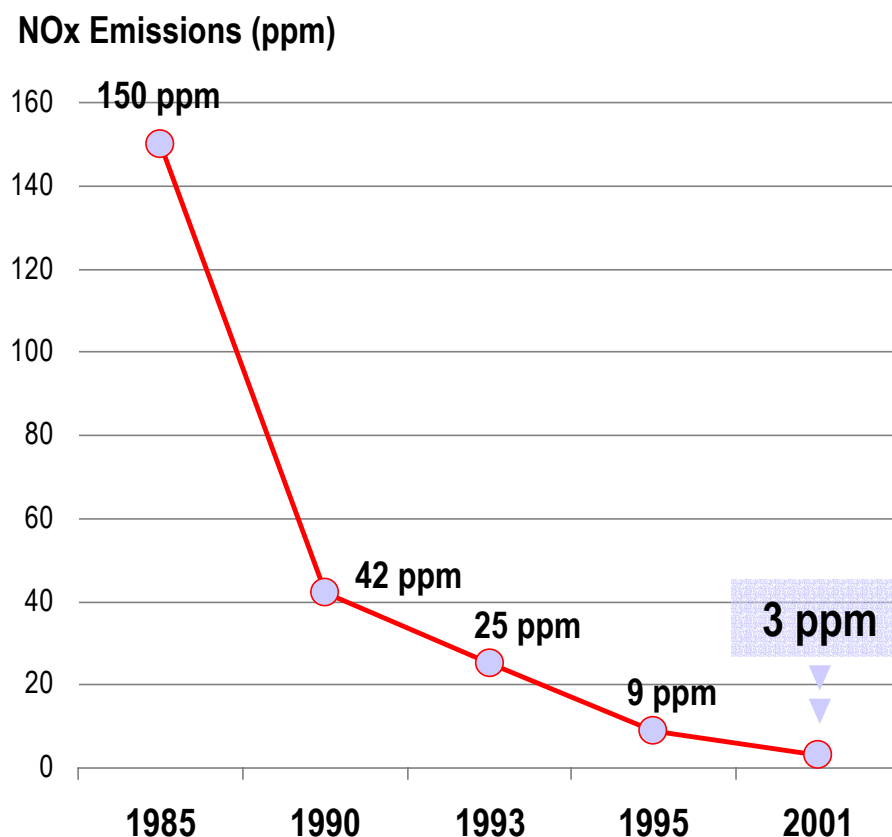
October 2002



More Restrictive Environmental Requirements

- Power generation significant contributor to air pollution
- Regulations focused on NOx
- Federal regulations enforce BACT/LAER in new permit applications
 - Offsetting creates economic incentive to do even better
- Key economic factor for generators
 - Permitting/siting
 - Cost structure
 - Operating flexibility

NOx Emissions Requirement Trend^(a)



(a) Based on US EPA BACT/LAER Clearinghouse data.



New Regulations Expand NO_x Restrictions



◆ Restrictions expanding geographically

◆ 8-Hour Ozone Standard

- ◆ Primary target is NO_x
- ◆ Impact in 2004

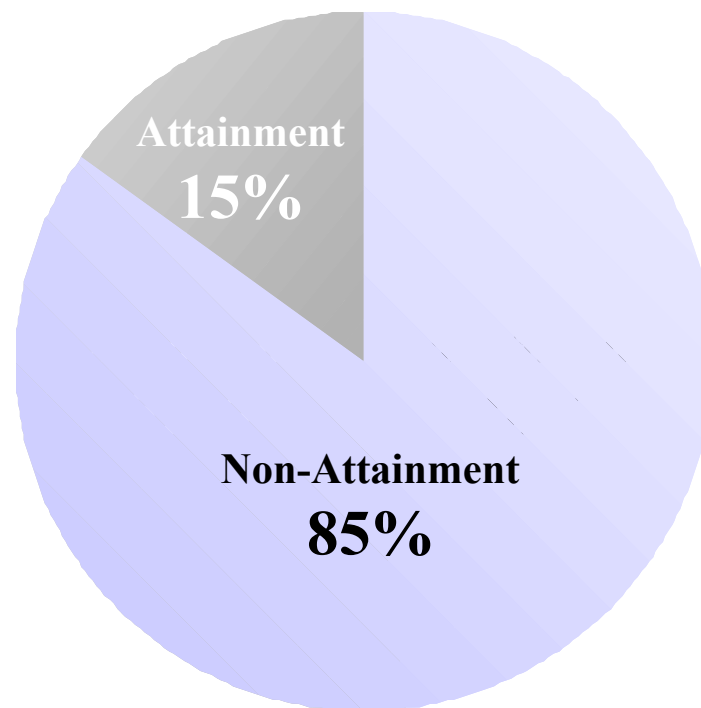
◆ NO_x SIP Call (OTC compliance)

- Major NO_x reductions in 19 states + DC
- Begin to implement controls - April '04
- Reach compliance – Sept. '07

◆ Bush Administration's Clear Skies Initiative

- Revises New Source Review (NSR)
- Cap & Trade Program
 - Creates attractive market for NO_x reductions
- Multi-pollutant legislation (NO_x, SO₂, Mercury)
 - Makes gas turbine installations more economically attractive

U.S. Population in Ozone Non-Attainment Areas



Impact of 8-hour Ozone Standard



INNOVATIVE TECHNOLOGY PROVIDES SUPERIOR SOLUTION
Breakthrough Catalytic Combustion



Ultra-low NO_x (< 3 ppm)

***Pollution Prevention Vs.
Exhaust Cleanup***

Cost Advantage

Scalable

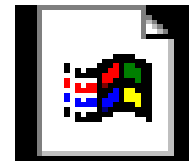
Xonon
Cool Combustion

Replaceable (~8,000 hours)



Catalytica Movie

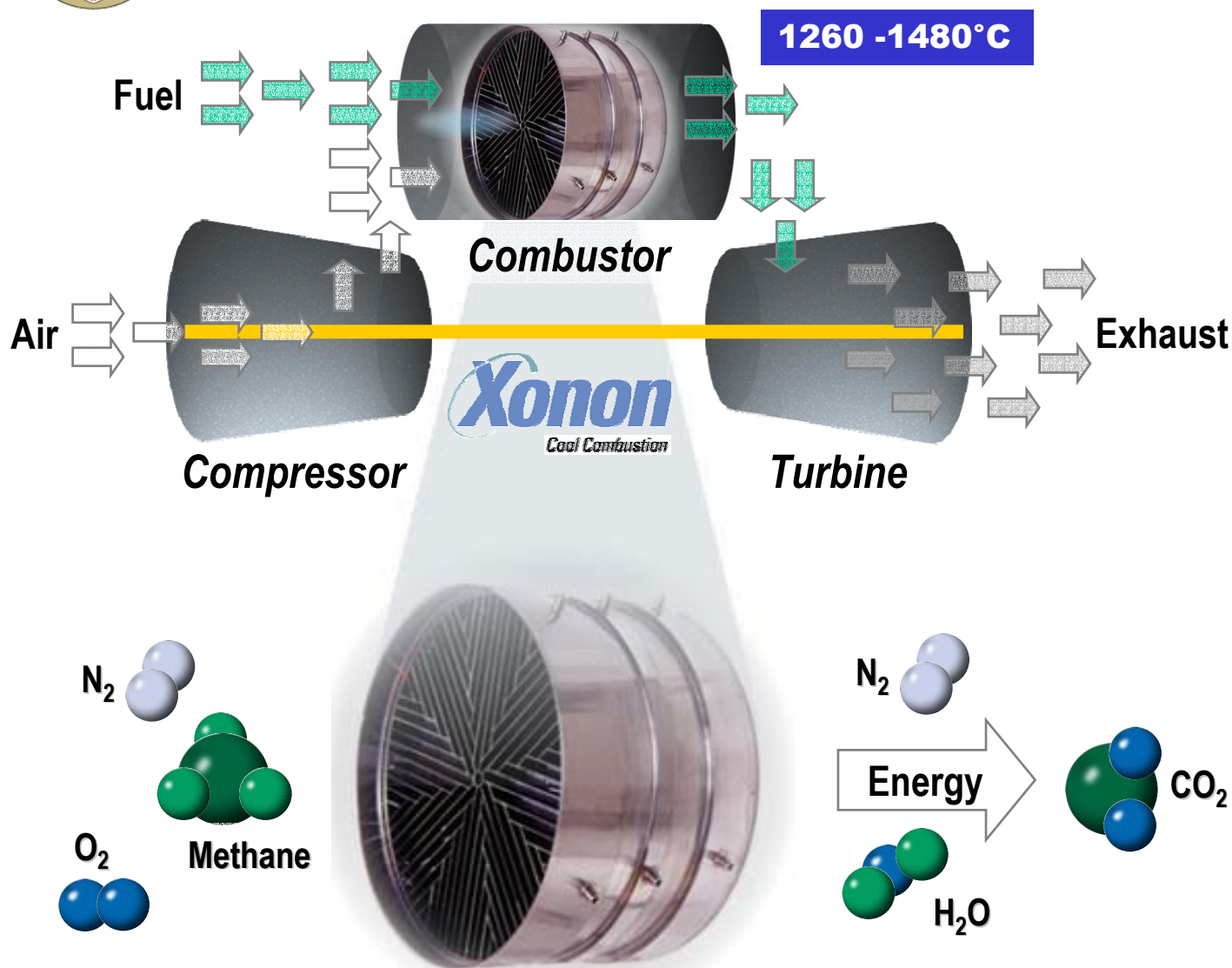
To view a 3 minute video on Catalytica's Xonon Combustor please doubleclick the icon to the right.



xonon_multi.asx

You must be connected to the web for the video to play.

How Xonon Works



**Flameless
combustion at
controlled
temperature**

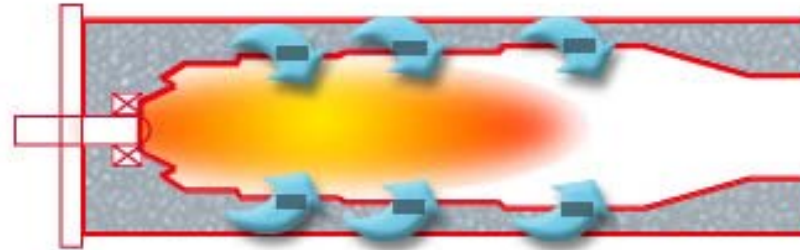
< 3 ppm NOx

**Nitrogen
unchanged so no
NOx is created**

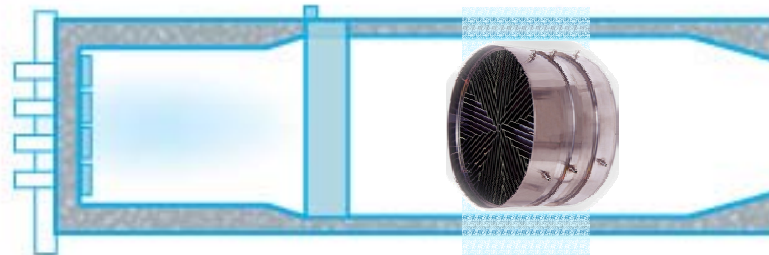
**Equivalent energy
output**

How Xonon Is Different

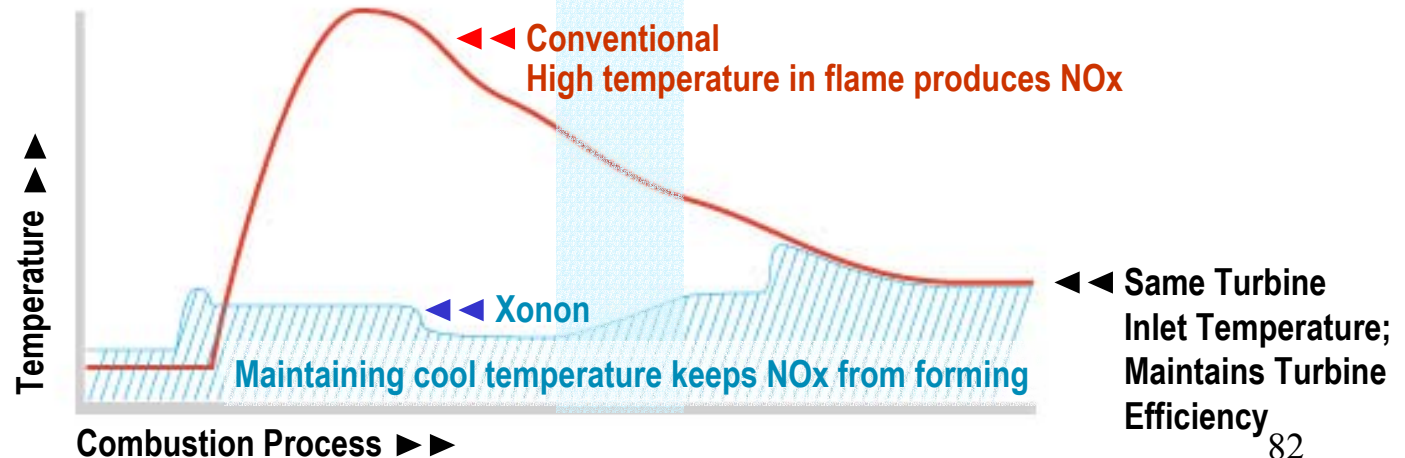
**Conventional
Combustor**



Xonon
Cool Combustion



**Performance
Comparison**





Cleanup Requires a Two-Step Approach



Flame-Based
Combustion

+ **DLN**



=

9 - 25 ppm NOx

+

SCR



EMx™ (aka SCONOx)

OR

<5 ppm NOx

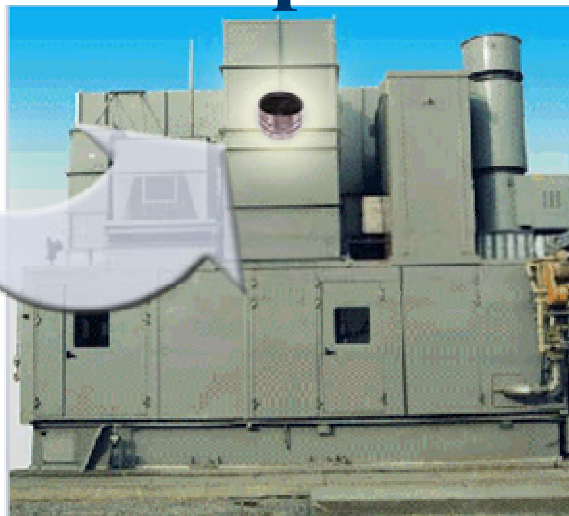




The Benefits of Prevention Over Cleanup



28" Diameter



=

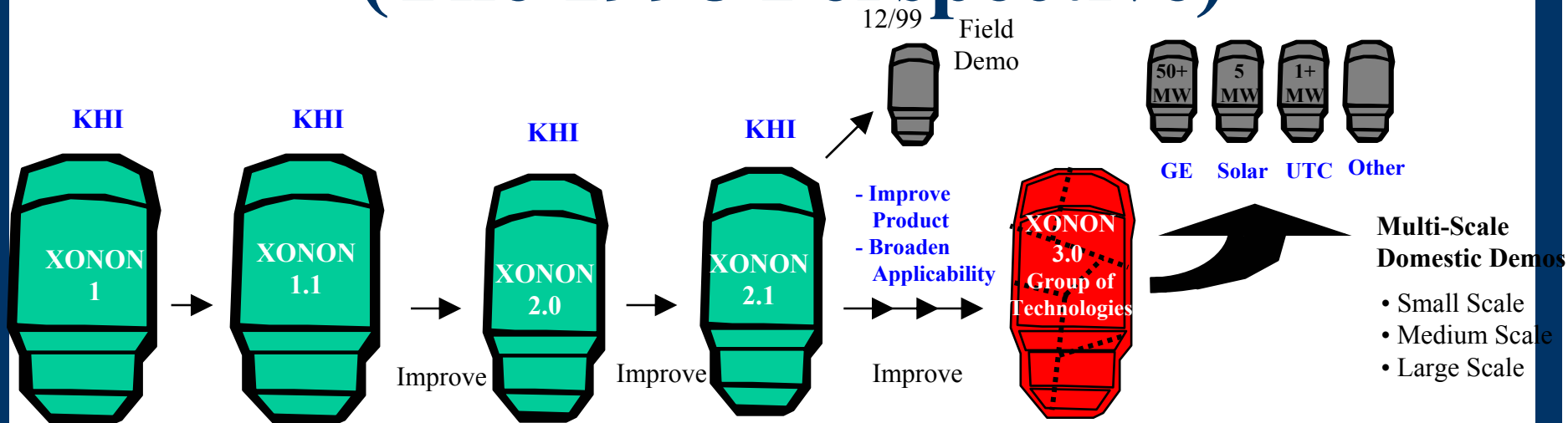
< 3 ppm NO_x

Xonon Advantages

- One-step approach
- Maintains turbine efficiency
- No additional footprint / ancillary equipment
- No toxic chemicals / no adverse environmental, health, safety or aesthetic impact
- Facilitates siting and permitting
- Enables operating flexibility
- Broader application potential
 - Combined cycle, simple cycle and distributed generation
- More cost-effective



Xonon Commercialization Funding (The 1998 Perspective)



Oklahoma (1000hrs) Silicon Valley Power
Test Cell



INITIAL FUNDING

- CARB
- ATS (DOE & CEC)

RAMD TEST FUNDING

- CEC, DOE & GRI
(separate contracts)

COMMERCIALIZATION PATH FUNDING

- CEC, DOE & GRI
(joint collaboration)

**XONON 3.0 will Offer
Manufacturers the Best:**

- **Premixing System**
- **Pre-Burner System**
- **Combustor System**
- **Catalyst System**
- **Control System**
- **Packaging**



Silicon Valley Power Results

RAMD: Reliability, Availability, Maintainability, Durability (CEC Program)

Performance Criteria	Results
RAMD Operating Hours	> 8100
NOx emissions	< 2.5 ppm (corrected to 15% O ₂)
CO emissions	< 6 ppm (corrected to 15% O ₂)
VOC emissions	< 3 ppm
Reliability ¹	> 98%
Reliability ²	> 99%

¹ Total turbine engine and Xonon system reliability

² Xonon combustion system reliability



RECENT ACHIEVEMENTS



Continued Success in Field Trials

Silicon Valley Power

- ◆ Xonon is proven on the grid
- ◆ 12,000+ hours, powering 1,500+ homes
- ◆ **ET** ✓ Consistently < 2.5 ppm
- ◆ 99%+ reliability
- ◆ Satisfied EPA's "Achieved in





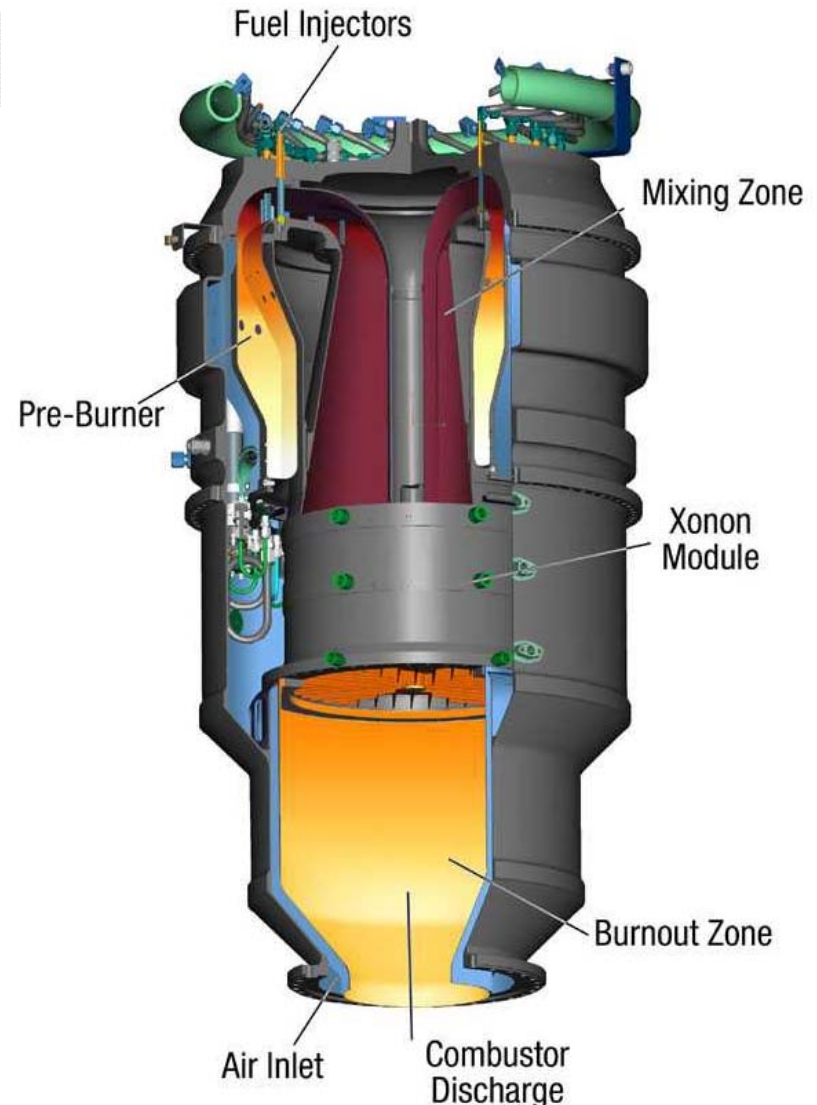
RECENT ACHIEVEMENTS



Advanced Product Development

Silicon Valley Power

- **>4600 hours of additional system and component testing**
- **Catalyst durability testing**
- **Combustion system component durability testing (e.g. pre-burner, mixer, bypass, etc.)**
- **Demonstration and refinement of control logic**
- **Development testing of new catalyst designs**
- **Continued validation of catalyst operating specifications (e.g. fuel, oil, air, etc.)**





RECENT ACHIEVEMENTS



Building Commercial Momentum

1.4 MW M1A-13X Commercially Available

- ◆ Included in CPUC subsidy for self-generation
- ◆ 1st commercial application expected Q4 2002
- ◆ Pursuing a number of additional projects for Xonon-equipped M1A-13X

Kawasaki
Gas Turbines





RECENT ACHIEVEMENTS



Expanding Xonon Market Presence

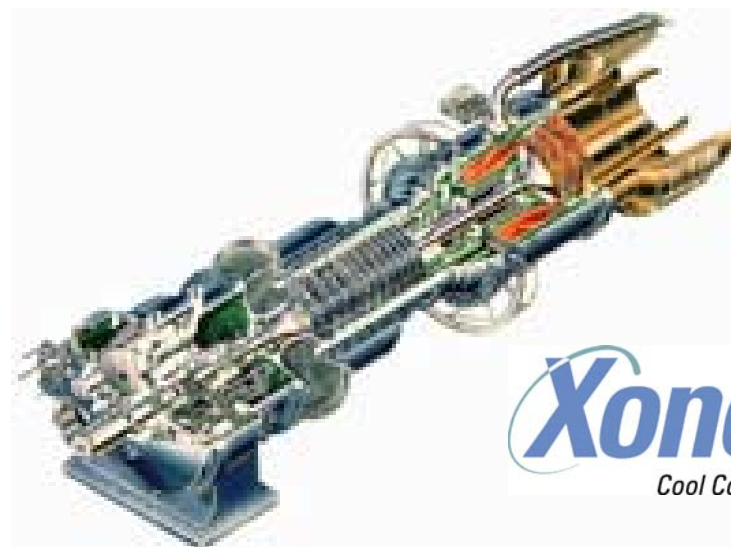
New Turbine Model Applications

**Leading Worldwide
Producer of Gas Turbines
in the 1-14 MW Size Range^(a)**

- ◆ **New agreement with Solar Turbines**
 - ◆ Taurus™ Engine (5-7 MW)
 - ◆ 24-month development launched Q2 2002
 - ◆ \$3.0 million CEC contract
- ◆ **Additional Efforts:**
 - ◆ Small, multi-can development program
 - Receipt of \$3 million award from CEC
 - Program launched in Q2 2002
 - ◆ Catalytic pilot (DOE funding 2000-02)

Solar® Turbines

A Caterpillar Company



Xonon
Cool Combustion

(a) Source: Solar Turbines website



RECENT ACHIEVEMENTS



On-Going OEM Program Progress

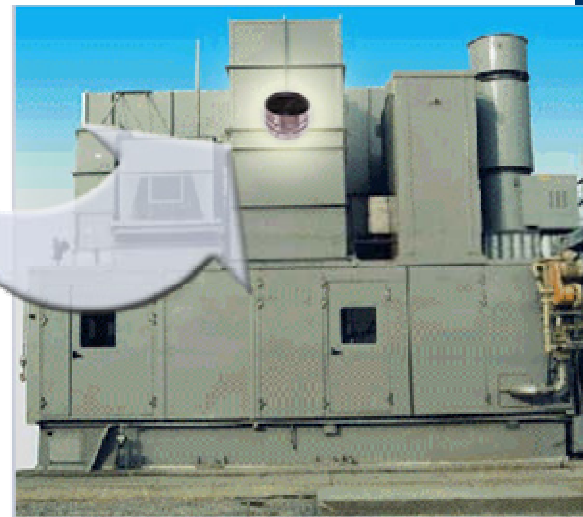
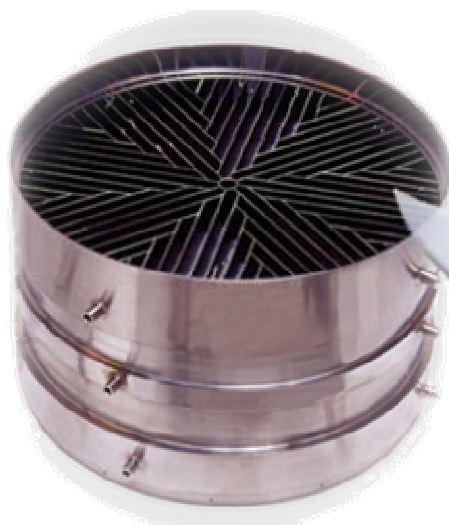
GE Power Systems

◆ GE10

- ◆ Completed 1st round of pre-launch testing Q3 2001
- ◆ 2nd round of testing now underway
- ◆ Commercially offer Xonon-equipped GE10 in 2003
- ◆ GE10 will lead Xonon evolution throughout fleet



GE Power Systems

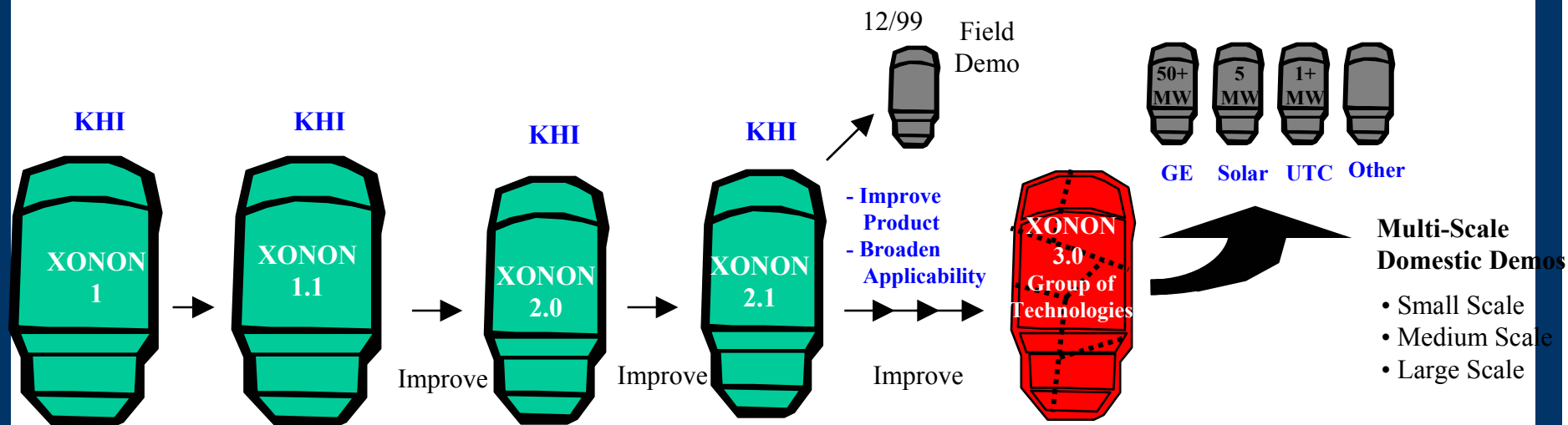


Xonon-Equipped GE10

(a) Source: GE Power Systems website.



Xonon Commercialization Funding (Where We Were In 1998)



Oklahoma (1000hrs) Silicon Valley Power
Test Cell



INITIAL FUNDING

- CARB
- ATS (DOE & CEC)

RAMD TEST FUNDING

- CEC, DOE & GRI
(separate contracts)

COMMERCIALIZATION PATH FUNDING

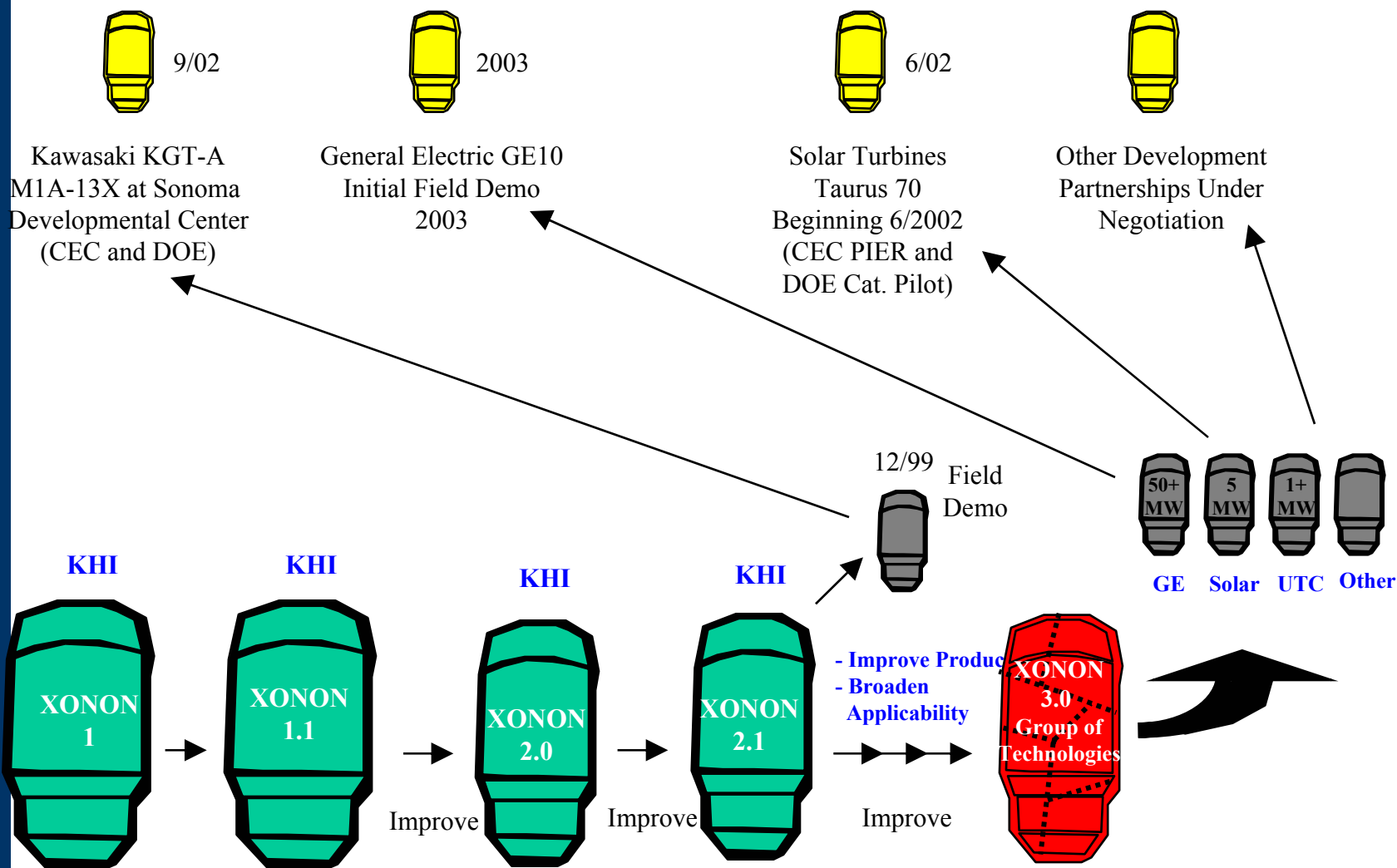
- CEC, DOE & GRI
(joint collaboration)

**XONON 3.0 will Offer
Manufacturers the Best:**

- **Premixing System**
- **Pre-Burner System**
- **Combustor System**
- **Catalyst System**
- **Control System**
- **Packaging**



Xonon Commercialization Funding (Where We Are Today)





Entering The Market



Barriers To Commercial Success

Market Uncertainties For Distributed Generation

- ◆ **Utility standby charges**
- ◆ **Exit fees on departing load**
- ◆ **Interconnection fees**
- ◆ **Interconnection procedures**
- ◆ **Uncertainty**





Entering The Market



Partnerships For Success

Vital Relationships That Go Beyond the Status Quo

- ◆ **Suppliers can't go it alone**
- ◆ **Suppliers need early stage support to develop technology prior to required partnership with OEMs**
- ◆ **OEM partnership is essential in later stages of**





RECENT ACHIEVEMENTS



Expanding our Product Pipeline

Broadening Xonon Application to New Markets



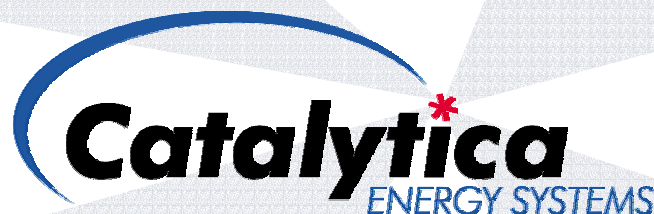
Fuel Processor

- \$11.7 mm DOE contract
- 48-month development
- 10 kW fuel processor prototype for use with fuel cells in vehicular applications



Diesels

- In development with leading diesel manufacturer
- Prototype demonstration scheduled this year
- Transferable to stationary diesels



Stationary Hybrids

- Gas turbine hybrid / fuel cell farms
- Contract with leading fuel cell manufacturer



Micro-Turbines

- Xonon technology applicable to microturbines
- Discussions with leading micro-turbine manufacturer



Clean Energy Systems Zero-Emission Gas Generator

John Henry Beyer
California Energy Commission
Research & Development Office
Public Interest Energy Research Program



Clean Energy Systems Gas Generator

Technical Approach

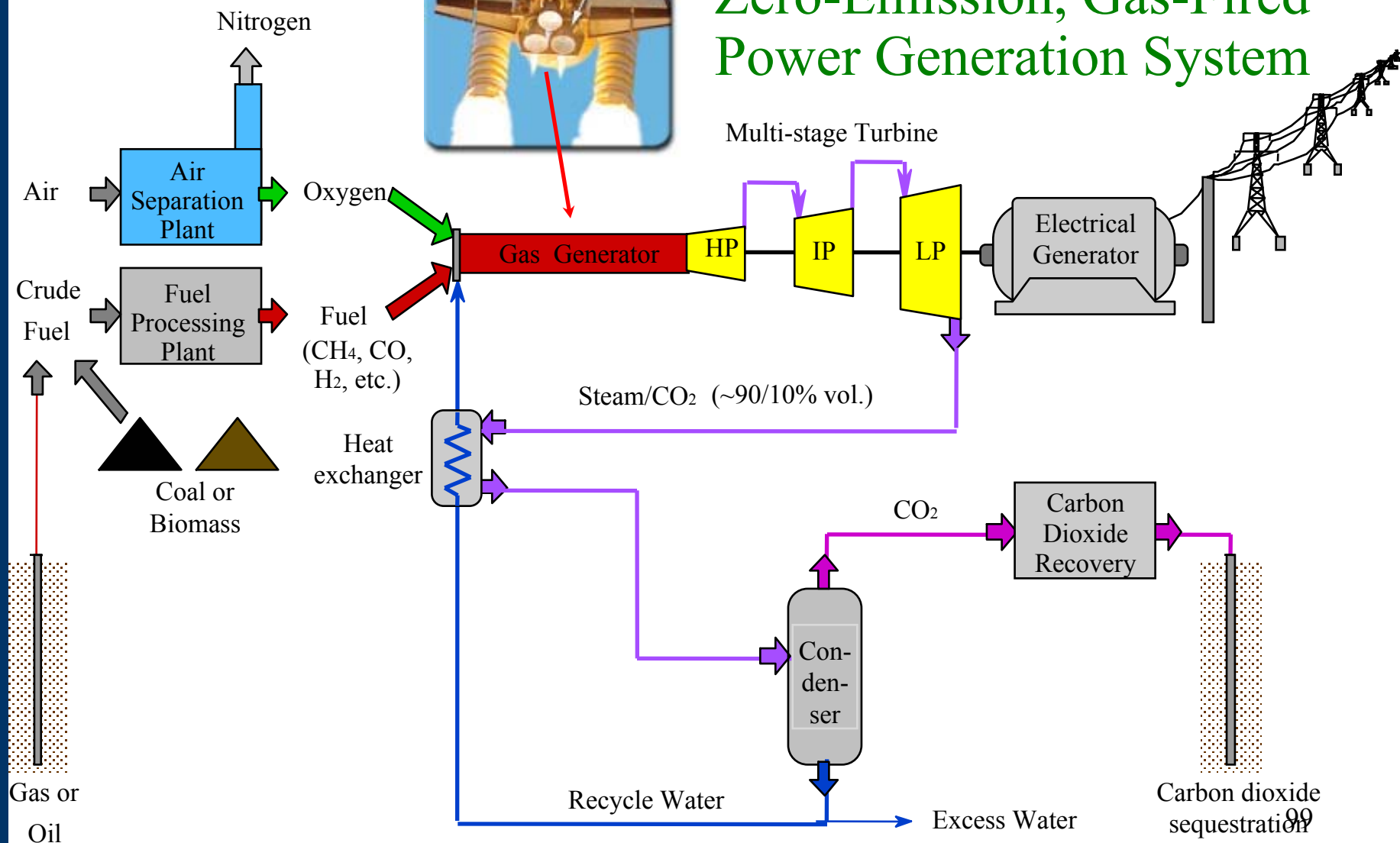


- ◆ Rocket engine technology utilized to generate electricity
- ◆ Fossil fuels combusted with oxygen — no NO_x , SO_x , UHC, negligible CO produced
- ◆ Drive gas is high temperature steam and CO_2
- ◆ Steam is condensed and recycled
- ◆ CO_2 is captured for sequestration or commercial use
- ◆ Zero emissions enables minimal environmental impact — negligible effect on air and water quality



Clean Energy Systems **pier**

Zero-Emission, Gas-Fired Power Generation System





Clean Energy Systems Gas Generator Economics



- ◆ Majority of CES power plant uses conventional equipment — steam turbines, generators, condensers, switch gear
- ◆ New equipment — O₂ separation plant and CO₂ recovery systems
- ◆ Relative CES plant efficiencies (including power consumption for O₂ separation and CO₂ sequestration) assuming the availability of:
 - *Current* steam turbines — CES competitive with “green” power including wind, solar, geothermal
 - *Near-term* steam turbines — CES competitive with CCGT (CCGT not required to capture CO₂ emissions)
 - *Advanced* steam turbines — CES efficiency exceeds advanced CCGT (CCGT not required to capture CO₂ emissions)



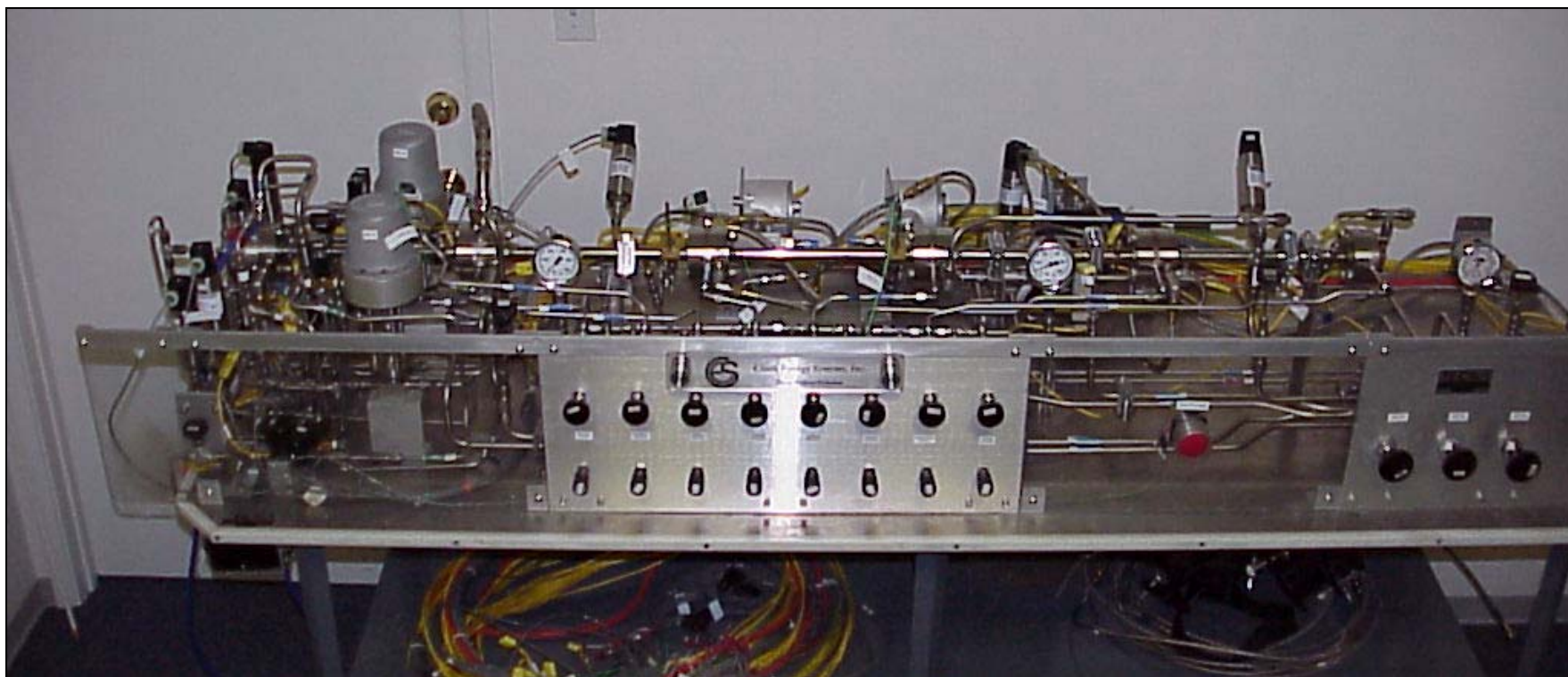
Long Term Benefits

- ◆ If a carbon tax is imposed or CO₂ sequestration is required, CES technology gains an immediate economic advantage — lowest cost of CO₂ capture
- ◆ Enhanced Oil Recovery (EOR) — Oil companies currently utilize significant amounts of CO₂ for tertiary oil recovery
 - ➔ Existing source of CO₂ for EOR injection is naturally occurring CO₂ from deep wells (not available in CA)
 - ➔ 100-200 MW CES plant could supply CO₂ needs of a medium oil field



CES 110 kW Gas Generator

Tested via PIER Energy Innovations Small Grant (EISG) Program, 2000-2001





Demonstration of a 500 kW Zero-Emission Gas-Fired Power Plant, 2002-2005

CEC Project Sponsors



Clean Energy Systems, Inc.



Air Liquide



Mirant Delta, LLC



**California Energy
Commission**



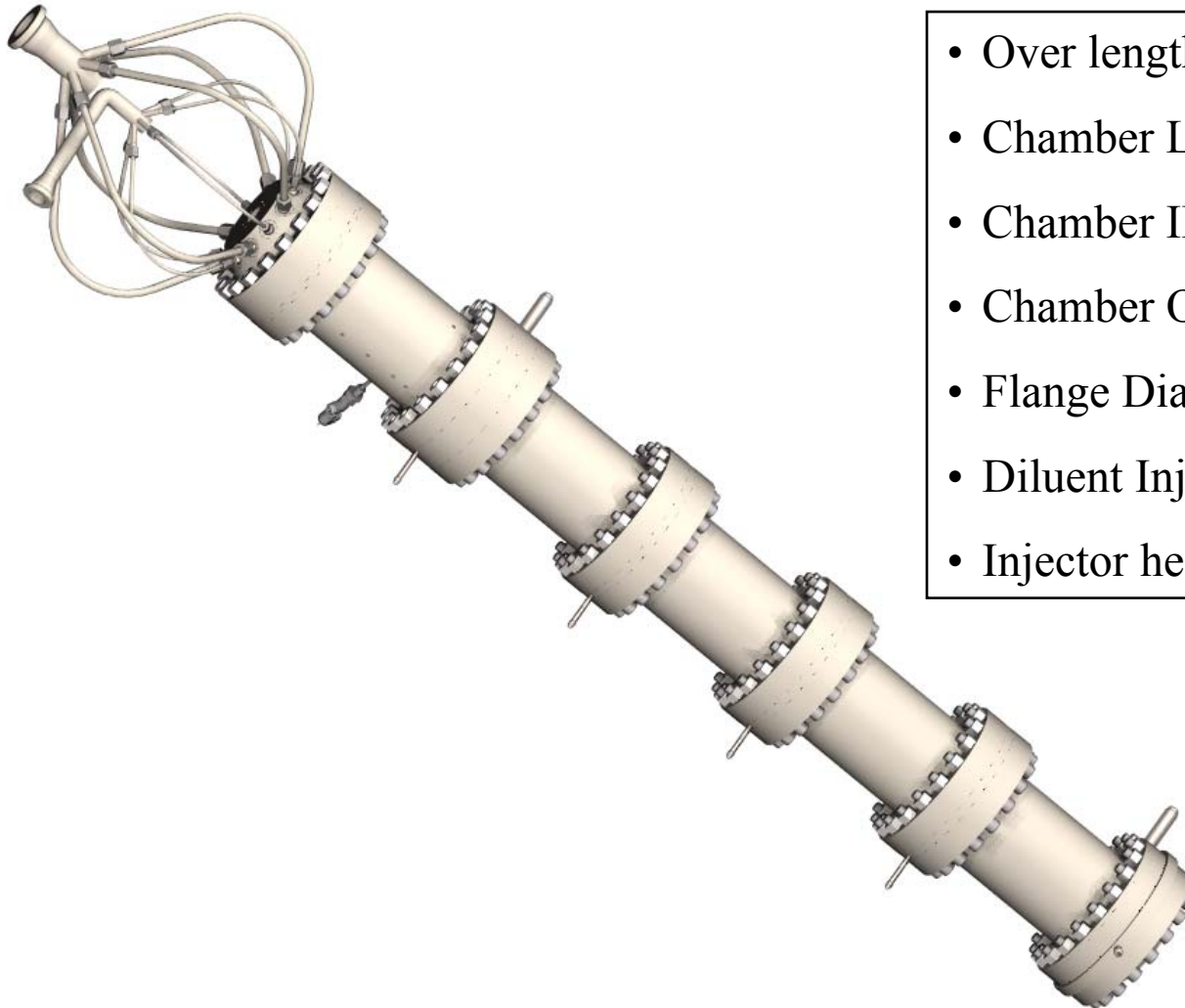


500 kW Power Plant Location Mirant Corporation, Antioch, CA





500 kW Gas Generator Durability/Reliability Demonstration



- Over length - 78"
- Chamber Lengths - 12"
- Chamber ID - 4"
- Chamber OD - 6.5"
- Flange Diameter - 10"
- Diluent Injector - 0.5"
- Injector height - 4"



CES Gas Generator Funding

CEC PIER

- ◆ EISG: 110 kW proof-of-concept (\$300K) \$75,000
- ◆ EPAG: 2-year durability/reliability demonstration of 500 kW power plant (\$4.5M) \$2,003,286

DOE

- ◆ Vision 21: 10 MW GG fabrication & test (\$3.7M) \$2,493,678
- ◆ LLNL National Test Facility - ZEST \$2,900,000
- ◆ NETL: Reheater for CES system \$800,000



CEC Antioch Gas Generator Funding

- ◆ **Leverages previous EISG, DOE, and corporate funding of CES technology (\$4.0M)**
- ◆ **Provides “bridge-funding” between technology demonstrations (110kW Proof-of-Principal, 10MW GG) and commercially proven product**
- ◆ **Joins corporate sponsors of demonstration — CES, Mirant, and Air Liquide**



California Energy Commission

Leveraging DOE and Private Funding to Advance Commercialization of CES Gas Generator Technology

Ronald Bischoff, CES

108



CEC Support for CES Commercialization



◆ Funding Support

◆ CES Milestones Support

CEC

◆ Concept Development

◆ Proof-of-Principle Test (\$75K)

Co-funded

◆ Commercial Scale Gas

◆ Generator (10 MW)

◆ Plant Durability Demo Demo (\$2M)

Co-funded



Mission



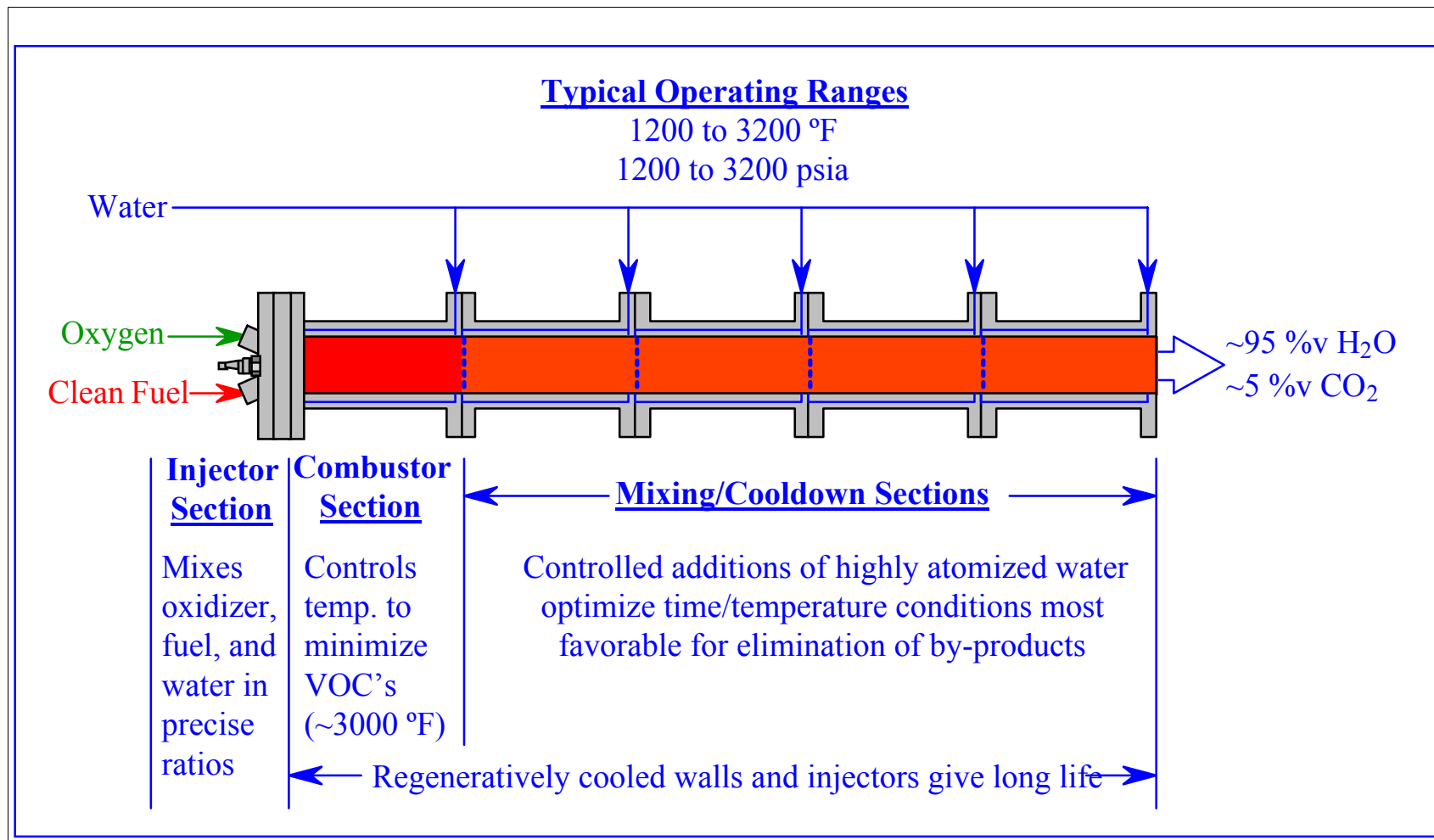
Clean Energy Systems, Inc. (CES)

*An advanced technology innovation company,
serving the global power market with proprietary
zero-emission processes and equipment.*

- Transfer proven space propulsion technology to commercial production of clean power
- Enable true zero-emission power plants which utilize fossil fuels



Schematic Diagram of CES Gas Generator





CEC Support for CES Commercialization

◆ Funding Support

◆ CES Milestones CEC Support

◆ **Concept Development** -----

◆ Proof-of-Principle Co-funded
Test (\$75K)

◆ **10 MW Gas Generator Fab/Test** -----

◆ **Plant Durability Demo** **Co-funded**
Demo (\$2M)



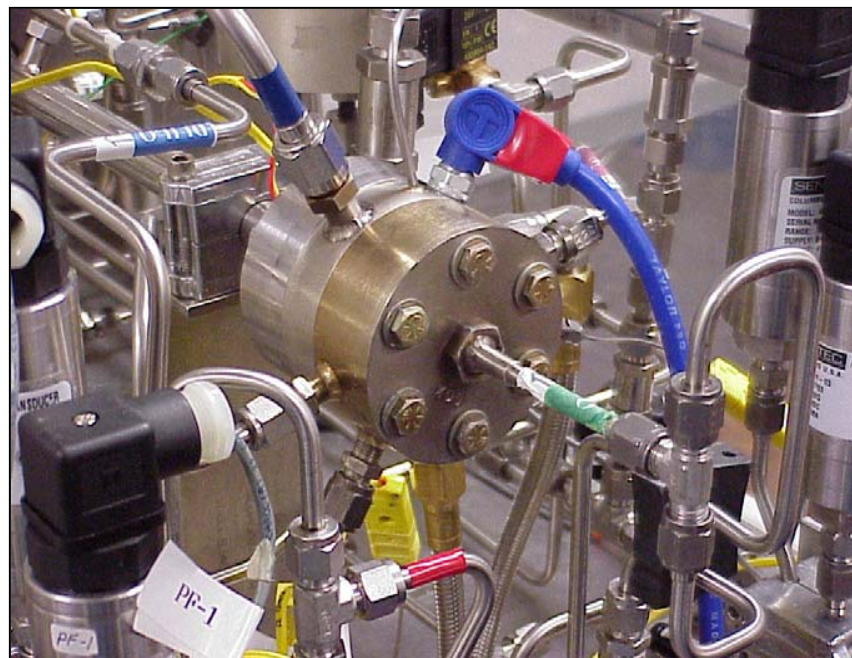
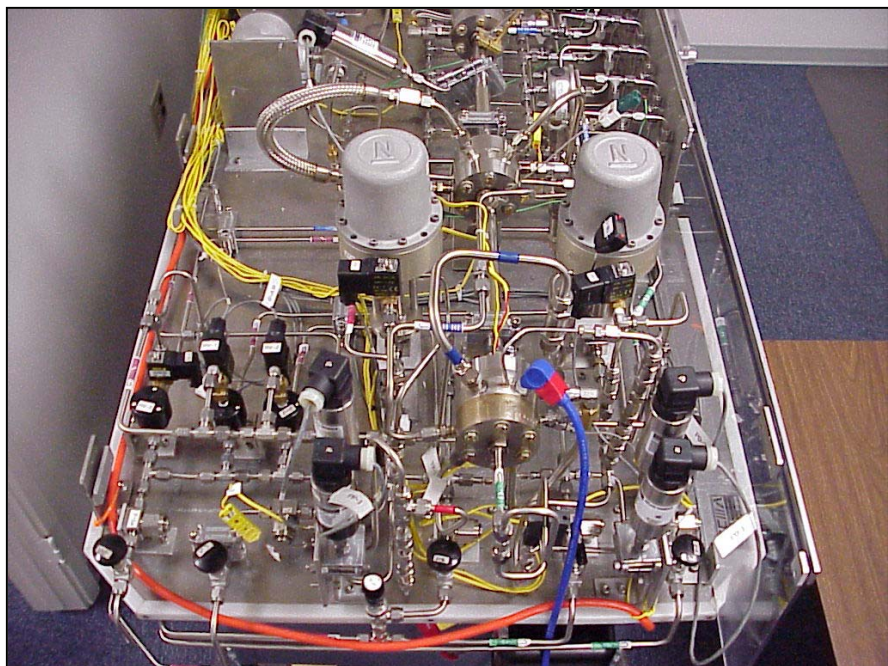
110 kW Gas Generator Test Program



- Jointly funded by CES and California Energy Commission (Energy Innovations Small Grant Program)
- Program Objectives:
 - Demonstrate premixing injector element design
 - Demonstrate time-temperature process control in cool-down modules to promote by-product re-association
- CES built a lab-scale 110kW GG, CEC funded test bench



110 kW Gas Generator Test Program





110 kW Gas Generator Test Program



Results:

- Demonstrated pre-mixing of O₂, fuel, water, with repeatable ignition & stable combustion
- Burned stoichiometrically for up to 45 min, with local flame temperatures ~ 6000 ° F
- Demonstrated stable, adjustable exit temperatures up to 2700°F at pressures to 300 psia
- Demonstrated gas sampling, analysis, and control systems
- Test successfully concluded January 2001 at UC Davis



CEC Support for CES Commercialization



◆ Funding Support

◆ CES Milestones Support

CEC

◆ Concept Development

◆ Proof-of-Principle Test (\$75K)

Co-funded

◆ 10MW Gas Generator Fab/Test

◆ Plant Durability Demo Demo (\$2M)

Co-funded



Vision 21 - 10 MW Gas Generator



- CES awarded \$2.7 million towards \$3.6 million program under DOE/NETL Vision 21 program

Program Objectives

- Design, fabricate and test a 10 MW gas generator
- Test Goals:
 - Achieve operating pressure of 1500 psia
 - Demonstrate temperatures from 1200 - 3000°F
 - Demonstrate reliable igniter performance
 - Test two main injector configurations (3rd as back-up)₁₁₇



Vision 21 - 10 MW Gas Generator

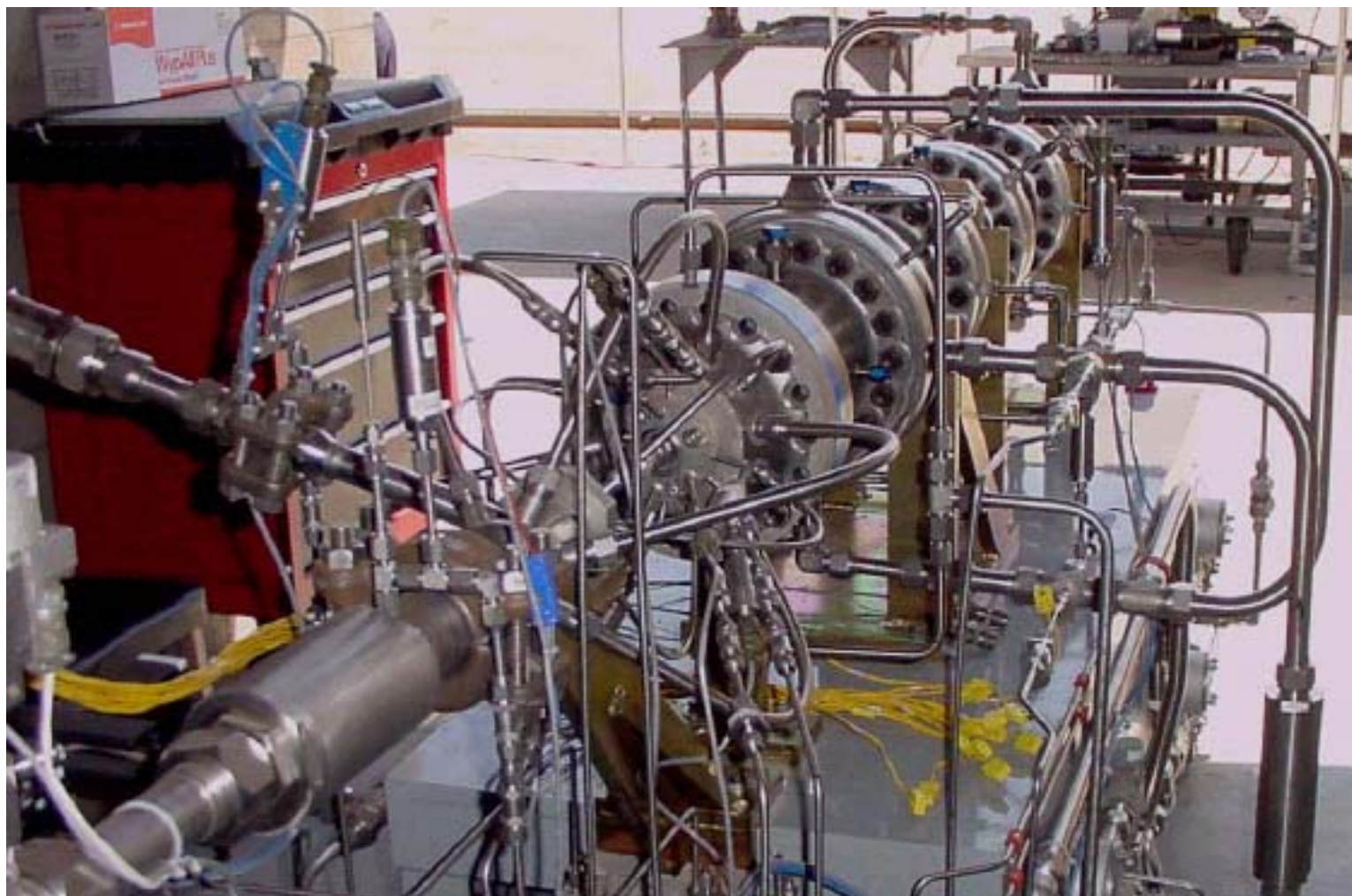


Results:

- GG fabricated and undergoing test at National Technical Systems, Santa Clarita, CA
- Igniter reliability demonstrated
- Two Main Injector configurations tested
 - Temperatures to 3000°F
 - Light-offs smooth with no pressure overshoots
- Full-up GG testing begins 18 Oct 2002
 - Test completion Nov 2002

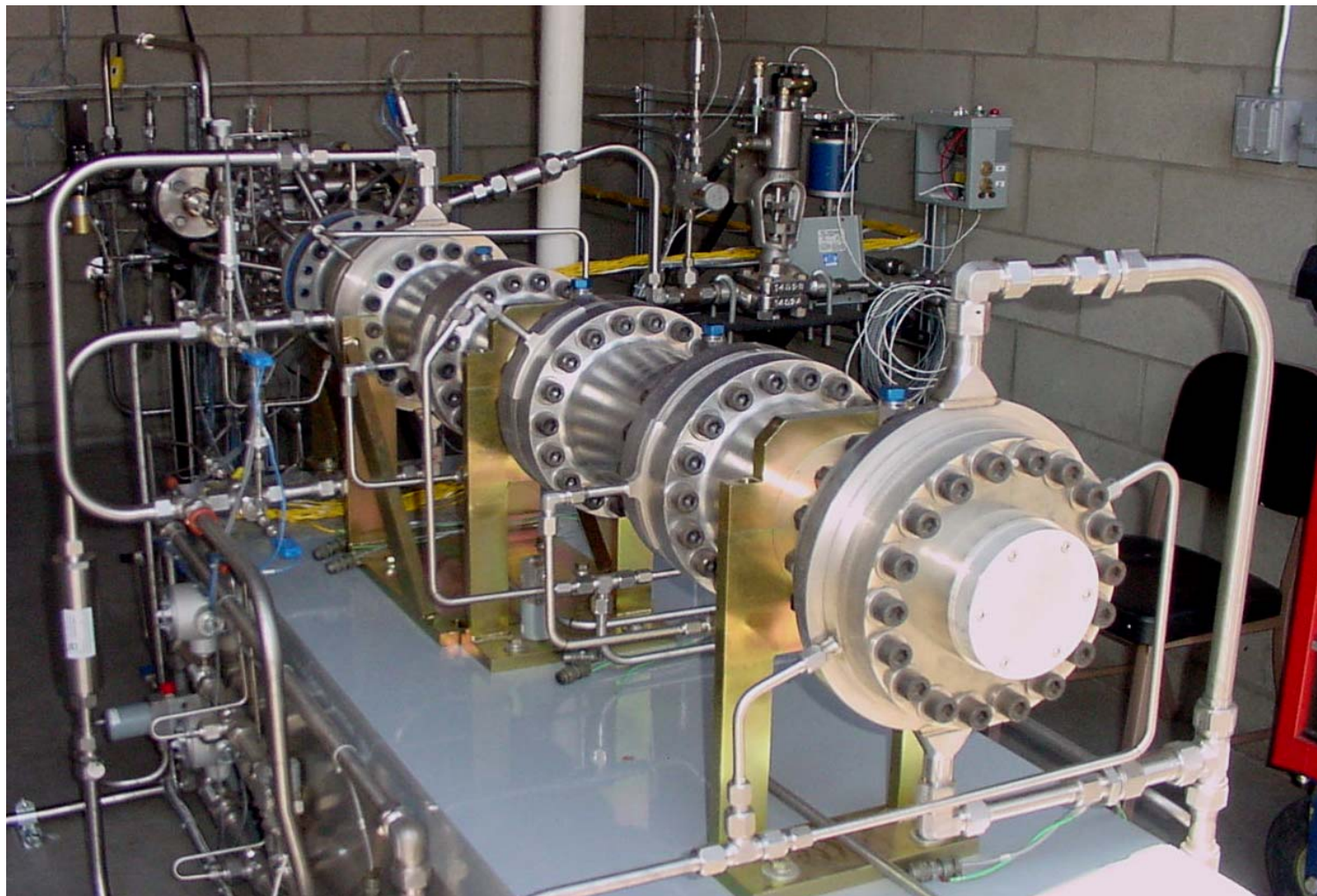


10 MW Gas Generator—Front View





10 MW Gas Generator—Aft View





CEC Support for CES Commercialization



◆ Funding Support

◆ CES Milestones CEC Support

◆ Concept Development -----

◆ Proof-of-Principle Test (\$75K) Co-funded

◆ 10MW Gas Generator Fab/Test -----

◆ Plant Durability Demo Co-funded Demo
(\$2M)



Antioch Zero-Emission Demonstration Power Plant



- **Program Objectives:**
 - **Design and fabricate 0.5 MW gas generator (GG)**
 - **Design and equip power plant utilizing O₂ as oxidizer and capturing CO₂ production**
 - ◆ **Conduct long-term GG durability testing (2 yrs)**
 - **Document commercialization approach**
 - Off-Design Characteristics Performance Report
 - Production Readiness Plan
 - Technology Transfer Plan



Antioch Zero-Emission Demonstration Power Plant



- **Status:**
- **- Contract awarded Feb 02**
- **Contract/Lease proposals in-place for major equipment**
- **Plant Milestones:**
 - Plant construction — Dec 02
 - Equipment installation — Mar 03
 - First electrical “synchronization” — Apr 03
 - 2-year plant demonstration — May 03 to May 05



The Next Steps



- ◆ **Inter-Turbine Re-heater**
 - Improves plant thermal efficiency
 - Developed & tested by DOE/NETL (Sep 02)
- **Zero Emission Coal Plant Development**
 - Utilizes gasified coal for zero-emission power production
 - Proposal pending at DOE/NETL – Jan 03 Selection
- **Cooperative Turbine Development**
 - 1500°F, 1500 psia high-pressure turbine
 - 2200F, 380 psia intermediate pressure turbine
- **Enhanced Hydrocarbon Fuel Recovery**
 - Enhanced Oil Recovery
 - Enhanced Coal-bed Methane Recovery



220 kWe Solid Oxide Fuel Cell/Microturbine Generator Hybrid Proof of Concept Demonstration

**Southern California Edison
Company
PIER Transition Project**



SOFC/MTG Hybrid Proof of Concept

**SOFC/MTG Hybrids have the potential for
low cost (for the MTG), high efficiency
(60%+ by using topping or bottoming
cycles) and low atmospheric emissions**

But...

SOFCs and MTGs operate very differently
System controls must be sophisticated



SOFC/MTG Hybrid

Proof of Concept Continued

**S/W 200 kW pressurized (3 atm) SOFC
Topping**

Ingersoll-Rand 75 kW MTG Bottoming

Larger than 50 kW required

SOFC exhaust gas to turbine inlet 1) drives air compressor to pressurize SOFC and 2) drives a power turbine



SOFC/MTG Hybrid

Proof of Concept Continued

52% efficiency vs. 57% design

1 ppm NO_x vs. 5 ppm goal

Multiple startups and shutdowns

Multiple failures of the SOFC occurred

Design improvements were identified

Proper match of MTG to SOFC

Improve controls

◆ **Successful Proof of Concept Demonstration**



EPAG Fuel Cell Direction



- PEMFC, MCFC and SOFC all show promise
- Two CEC awards to Siemens/Westinghouse were never started
- EPAG has imposed public disclosure requirements on results of demonstration projects
- Intermediate temperature (about 650°C) SOFCs seem to be the most promising option for stationary and transportation applications



The S/W SOFC is Close to Commercial Introduction

- 1,000°C operation
- Low power density ($<0.3 \text{ W/cm}^2$)
- Requires ceramic materials
- Debate about economic viability because of processing, fabrication and materials utilization issues
- In the 1960s, high temperature fuel cell operation was supported by the DOE coal program for integrated coal gasification/SOFC operation



650°C SOFCs are not a New Idea



- By the mid 1960s, the potential of intermediate temperature SOFCs had been established
 - **Doped cerium oxide electrolytes had adequate ionic conductivity**
 - **Thin film electrolyte fabrication had been demonstrated**
 - **Potential to replace ceramics with metals was appreciated**
- IT SOFC development languished from the mid-1960s until the late 1980s



There is no Free Lunch



- Planar fuel cell stacks experience high thermal and mechanical stresses because cells are stacked one on top of another
- Sealing of gas manifolds to the stack is challenging
- New and compatible materials must be found for every component
- Natural gas reforming at 650°C requires a steam-to-carbon ratio above 3, and reaction kinetics are too low to support high current density



GTI is Half of a \$6 Million Bet



- ETAP RFP of April 2001 Targeted SOFCs with an Installed Capital Cost of \$800/kW and a Power Density $>0.3 \text{ W/cm}^2$ for 2005 and \$400/kW and Power Density $>0.5 \text{ W/cm}^2$ by 2010
- ETAP and SECA Cost Targets are the same, except that SECA 2005 Target is for a Prototype
- PIER Contracts were awarded to GTI and LLNL
- ETAP is not funding large teams, in contrast to SECA
- SECA is not funding GTI and is barely funding LLNL



Project History



- **1992, GTI/EPRI R&D initiated at U-Utah**
 - 1995, Focused development
- **11/98, \$3MM/3yr NIST-ATP contract**
- **1/99, GTI/EPRI/MSRI/U-Utah consortium**
 - Intellectual Property unified
 - Cell, stack, and interconnect patents issued
 - Non-GTI/EPRI contracts licensed to consortium
- **9/01, \$4.3 million/3yr GTI/MSRI/Nexant/Technologix/U-Utah Project with \$3 million PIER Award**
- **9/01, GTI/EPRI/MSRI/U-Utah form Versa Power Systems, Inc. to commercialize RTESP SOFCs**

**10 Cell, 4"x4", 500W
Internally Manifolded
Stack**

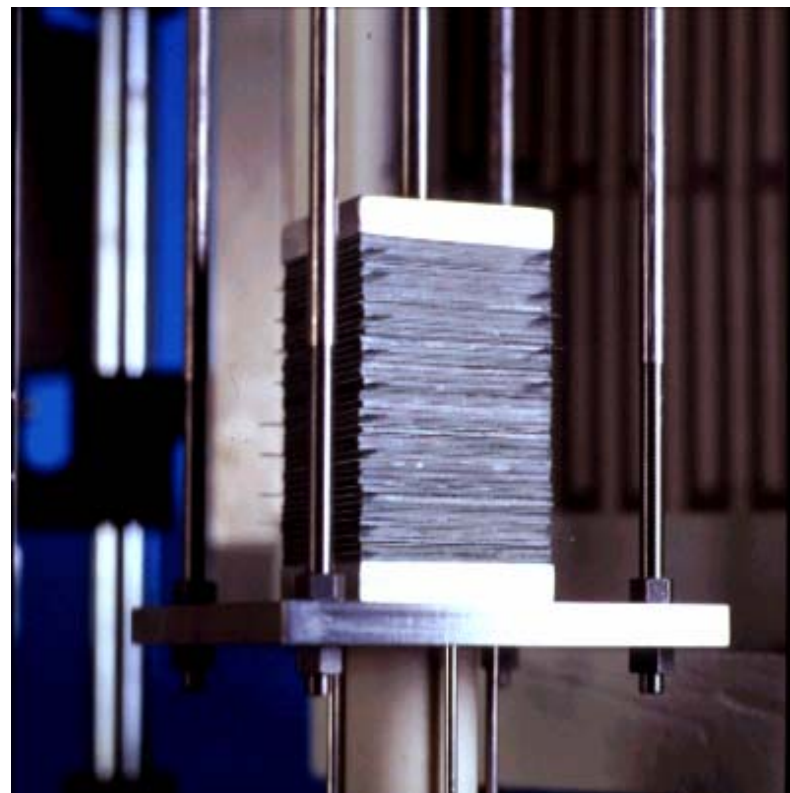




MSRI: Compact, Low-Cost SOFC



- Only U.S. internally manifolded, cross-flow RTESP SOFC stack
- Cell/Stack design minimizes sealing, and thermal cycling and expansion issues
- Cells and small stacks scaled-up to commercial, 4"x4" size
- Small stack power density has reached $\sim 0.7\text{W}/\text{cm}^2$
- State-of-the-art interconnects
- Multi-fuel capability



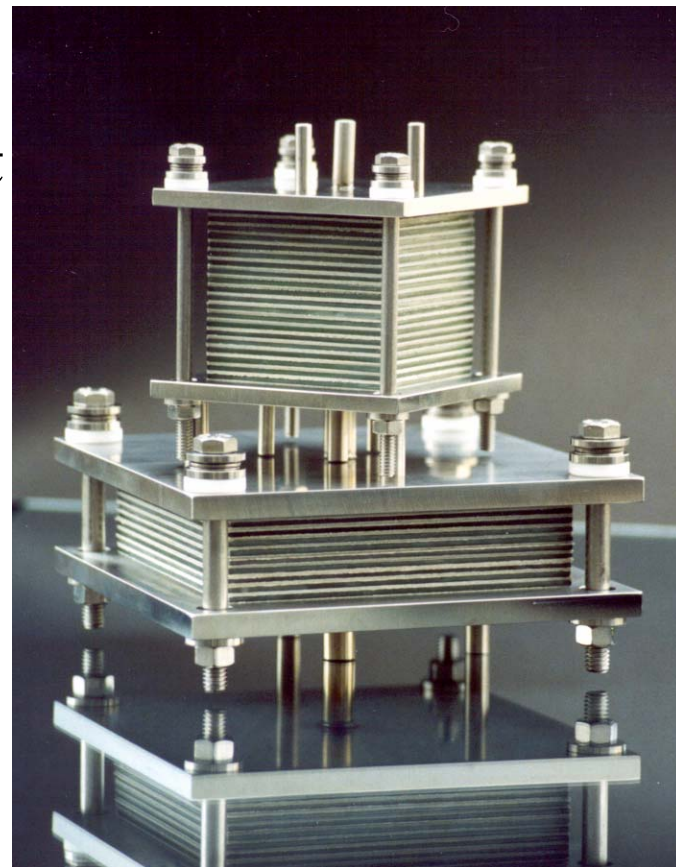
**Internally Manifolded
300W Stack**



GTI SOFC Contract Objective



- A sub-scale power module for a 10-kW SOFC system is to be developed
- Sub-scale module is a 1-3 kW test unit to demonstrate improved air and heat management
- The test unit includes stack, air-pre-heater and pre-burner and operates on mixed gases simulating various fuels
- MSRI is developing a lower operating temperature, high-power density stack for the test unit
- Potential for >10% points efficiency improvement and capital cost <\$700/kW

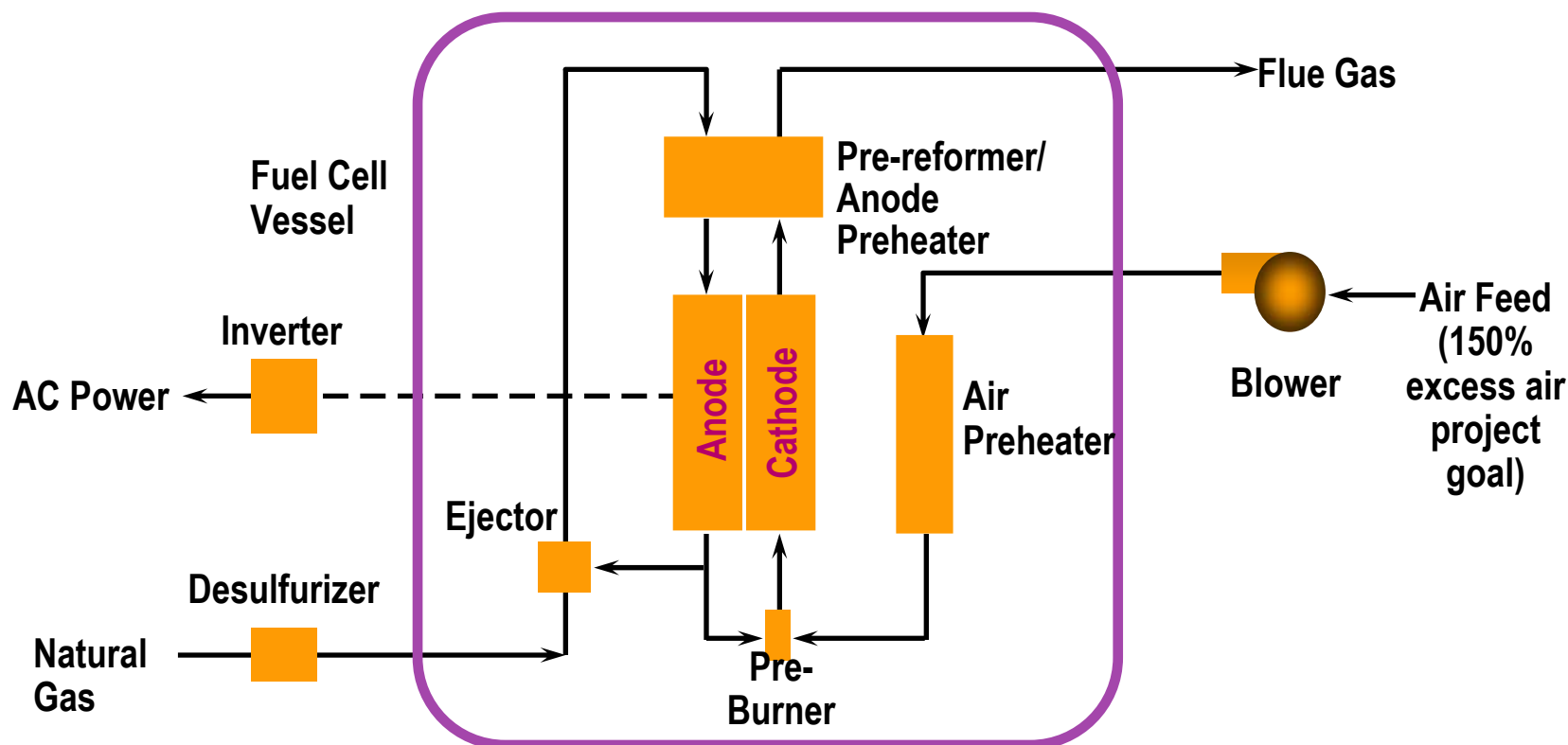


MSRI Stack Technology



System Configuration

(Ambient Pressure Operation)





GTI SOFC Contract Funding



**Cell Materials
Development
@ U-Utah,
\$200K PIER**

**Cell Production and
Stack Assembly @
MSRI, \$1800K PIER**

**Power Module
Testing @ GTI,
\$600K PIER +
\$1,309K cofunding**

**Stack Design @
Technologix, \$200K
PIER**

**System Design
@ Nexant,
\$200K PIER**



ASERTTI



(Association of State Energy Research and Technology Transfer Institutions, Inc)

Collaborative National Program for the Development and Performance Testing of Distributed Power Technologies

With Emphasis on Combined Heat and Power Applications



ASERTTI DG/CHP Project



**Collaboration of US Department of Energy,
CA Energy Commission , NY State Energy
Research and Development Authority, IL
Department of Commerce and Community
Affairs (represented by University of IL,
Chicago)**

**Result of competitive 2001 DOE
Solicitation**

Builds on Significant Work Done by Team



ASERTTI DG/CHP



Project Scope

Performance Testing Protocols for Distributed Generation Systems in Laboratory and Field Applications under various duty cycles

Microturbine generators, reciprocating engines, small turbines, fuel cells, then (maybe) PV, wind

Validation and Application of protocols by ASERTTI members

Internet-accessible publicly available database of performance data

Project Reports and Case Studies



ASERTTI DG/CHP

Project Goals



Nationally-Accepted DG Testing and Reporting Protocols

Accurate and unbiased performance information

Long term testing in diverse applications and climates, including RAMD characteristics

Utilize best national expertise



ASERTTI DG/CHP

Project Status



**DOE Golden Field Office Contract Awarded to
Energy Center of WI**

States continuing related projects as match

RFB issued for MTG/CHP Protocols

**Formation of Collaborative Team and
Stakeholder Groups major requirement**

Responses being evaluated

Award early November

**First effort may include MTGs, small turbines,
and reciprocating engines**



Technical Review Committee

Questions/Feedback

- ◆ Are EPAG's Mission, Vision, and Goals consistent with meeting CA needs?
- ◆ Is EPAG funding projects that have the potential to solve CA's energy-technology related problems?
- ◆ Are EPAG research efforts sufficiently coordinated and leveraged with those of other research organizations? If not, how can that be corrected?



Technical Review Committee

Questions/Feedback

- ◆ Will the planned portfolio lead to a technology mix with an appropriate balance to meet CA needs?
- ◆ Does EPAG's RD&D program address the right mix of short, medium, and long term energy issues in CA?
- ◆ Have we failed to identify areas for improvement?



Technical Review Committee

Questions/Feedback



- ◆ Is EPAG correctly applying lessons learned in future planning?
- ◆ How can EPAG do a better job of getting research results realized in the marketplace?



Please see the Appendix of Active EPAG Contracts for more information. It is a word file that is also on this disk.